THE

GEOLOGICAL MAGAZINE

NEW SERIES. DECADE VI. VOL. VI.

No. VII.—JULY, 1919.

EDITORIAL NOTES.

IN view of the interest aroused among geologists by the active political and press propaganda now in progress concerning the oil-borings in Derbyshire, it seemed advisable to publish forthwith the paper by Mr. V. C. Illing alluded to in our editorial last month. To do this necessitated the postponement of the second half of the paper on Potash by Dr. Holmes, begun in our June number, but Dr. Holmes has kindly consented to give precedence to his colleague in view of the urgency of the matter. Even by this arrangement the traditional balance of the Magazine has been somewhat upset, but the case is exceptional, and we do not intend to apologize for it. Our only concession is to cut down the editorial pages to a considerable extent, in order to prevent too much encroachment on the space allotted to reviews.

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WE are glad to note the election of Professor O. T. Jones, M.A., D.Sc., to the Professorship of Geology in the University of Manchester. Professor Jones graduated at Cambridge in 1902 and was subsequently awarded the Harkness Scholarship and the Sedgwick Prize; in 1903 he joined the Geological Survey of England, on which he served with distinction until 1910, when he was elected to the Professorship of Geology at University College, Aberystwyth. During his tenure of that chair he has discharged his duties with marked success and has published important papers on the Lower Palæozoic rocks of Wales. We wish him a prosperous career in his new position, where he will have increased opportunity to carry out geological work of various kinds.

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NOTWITHSTANDING the demands made by the War on the United States National Museum, the report for the year ending June 30, 1918, gives a record of much progress. Apart from the activities connected directly with the War, such as the selection of suitable vesicular rocks for use in the construction of concrete ships, the provision of technical information to Intelligence Bureaux, and the satisfying of demands from such State Departments as the Bureau of Standards and the Department of Agriculture, much has been accomplished for the Museum itself. In connexion with the collection of minerals of importance for war materials, an exhibit worthy of note is that of the largest mass of tungsten ore yet mined—a mass of scheelite weighing 2,614 pounds. Another notable addition is a collection of nearly ten thousand specimens

obtained by Dr. C. D. Walcott from the Middle Cambrian of Burgess Pass, British Columbia. From this locality also, a ton and a half of material was sent to the Museum as the result of last field-season's work. The quarry that yielded the best of the famous Middle Cambrian fossils is now practically exhausted. Details given of other results of the Museum's official "Explorations" show quite clearly the advantages that would accrue if corresponding features were organized in the big institutions of this country.

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So much unpublished information was accumulated by the Geological Survey of Western Australia, that the preparation of reports occupied a proportionately greater amount of the Staff's time than actual field-work (Annual Progress Report of the Geological Survey of Western Australia for 1917). This circumstance, combined with the fact that the activities of the Survey are becoming more and more of an economic nature, tend to show that some augmentation, in personnel at least, could be made with advantage. In addition to duties in the field and in the office, the Survey is conducting experiments on clays, potash minerals, etc., from which results of value to industry are expected. The Laboratory Report shows that highly satisfactory results are being attained; and in the year under review 1671 samples were registered, an increase of 20 per cent over the previous year. Among the results of the field-work recorded in the above-mentioned report, we read that wolfram, occurring as "floaters", has been found at a locality about 3 miles north of Grass Valley Township, on the Great Eastern Railway, east of Northam. The rocks in this neighbourhood are granitic, with a network of dolerite dykes; the surface is covered by a varying thickness of débris, which has prevented detailed mapping up to the present. It is thought that when the true matrix is discovered it will be a pegmatite.

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The election of Dr. Arthur Smith Woodward to the Presidency of the Linnean Society of London will be of great interest to geologists. Dr. Woodward filled the office of President of the Geological Society from 1914 to 1916, and has served a term as Vice-President of the Zoological Society.

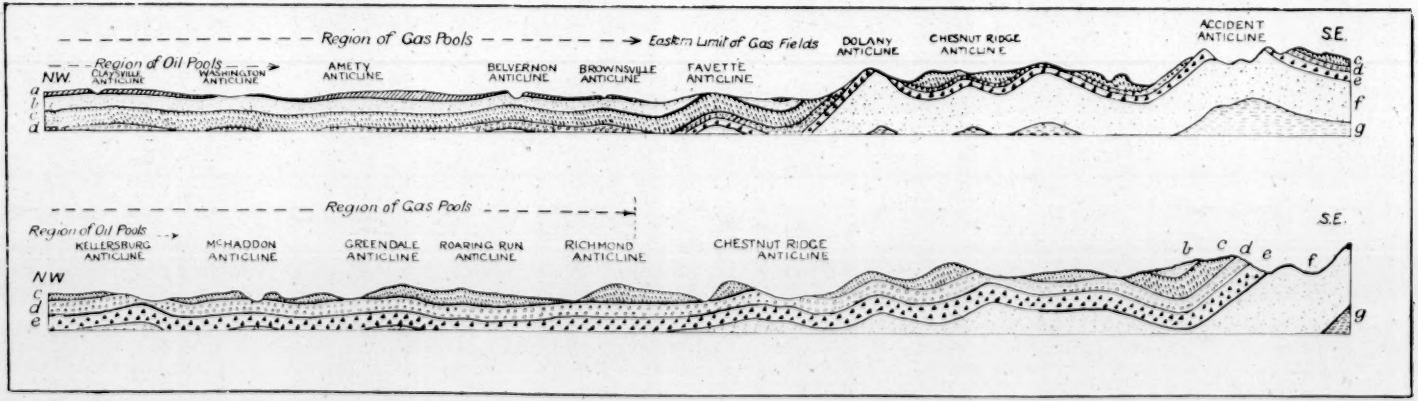
ORIGINAL ARTICLES.

I.—The Search for Subterranean "Oil-pools" in the British Isles.

By V. C. Illing, M.A., F.G.S.

(PLATE VII.)

IT is curious how readily the public misconceives even the most simple of scientific problems. A plausible theory, no matter how fallacious, will gain an immediate currency which it is difficult to undermine until it has run its course. Such theories do harm to the public, to industry, and to science, and they should be



V. C. Illing del.

SECTIONS ACROSS THE NORTHERN AND SOUTHERN OIL- AND GAS-FIELDS OF PENNSYLVANIA.

The vertical scale is exaggerated ten times. *a*, Permian; *b*, Pennsylvanian above Pittsburg Coal; *c*, *d*, Pennsylvanian below Pittsburg Coal; *e*, Mississippian (oil and gas); *f*, Upper Devonian (oil and gas); *g*, Middle Devonian. The sections illustrate the complete loss of oil and gas when the strata approach the eastern zone of folding.

combated rather than avoided, so that the mischief may be curtailed, if not entirely eliminated.

It is but a few years since the geologist and botanist were popularly regarded as mere dilettantes, dabblers in fossils and plants, harmless individuals with a craze for the useless. The recent problems of agriculture, timber, mineral resources, and water-supply have shown how essential are these sciences in the national economy, and the geologist and botanist have gained an assured place in industry beside the chemist and the physicist. This position implies responsibility of the collective body as well as of the individual, and it is becoming increasingly necessary that the opinion of organized science should be less inarticulate when matters in which it is interested become the subject of public discussion.

This is especially true of geology, the science directly concerned with the mineral wealth of the country, and no better example of this need can be found than the question recently raised of the possible occurrence of underground oil-pools in Great Britain. The subject is essentially a geological one, and the British School of Geologists holds no uncertain views about the project, yet these views have been completely overshadowed by the insistent utterances of a few individuals.

Geology is not an exact science. The personal factor looms so large in many of its problems that he must needs be hardy who dares to be positive, and inexperienced who considers his verdict a final solution. The paths of progress in geological thought are strewn with discarded theories, the working hypotheses of the individual in his search for truth. To confuse theory with fact, to pivot an immense industrial undertaking on the transitory opinions of a few individuals, when there is ample opportunity for a wider appeal, is poor policy. The appointment of a representative committee of scientists to discuss and report on the possibilities of finding commercial quantities of crude petroleum in the British Isles should have been a necessary preliminary to the whole undertaking.

In the maze of involved economic and political interests it is difficult and profitless to follow the drilling scheme from its inception to its adoption. Primarily it was essentially a war measure, a forlorn attempt caused by a desperate need, and to view it in any other light is to rob it of its main excuse for existence. To the geologist, however, the fact which matters is the problem itself, and the ultimate possibilities are sufficiently interesting to need no excuse for being intruded on the notice of the reader. It is obvious that the discovery of large pools of oil and gas in this country would be of great national importance. The mere possibility of success would be ample warrant for the public expenditure, but at the same time the problem should be examined with a calm discussion and judgment of facts to give pause to the wild hopes raised by the utterances of misguided optimism.

It is not difficult to surmise the main guiding principles which are being adopted in the present search for oil in Britain. The

chief reliance is being placed on the lower portion of the Carboniferous system, particularly the porous horizons of the Millstone Grit series and the Carboniferous Limestone. On the other hand, the Coal-Measures and Yoredale Shales, which respectively overlie these porous rocks, will be relied on to form impervious cover-rocks to prevent the oil and gas from escaping during the normal processes of denudation. The next stage in the undertaking is the examination of the tectonics of these Carboniferous rocks and the choosing of areas for drilling operations where the structures are suitable for oil and gas accumulation. Such areas are mainly anticlinal in form with an adequate thickness of undenuded impervious rocks on the crest of the fold. This almost necessarily implies drilling in the Coal-Measure basins on subsidiary anticlines in the main synclines. This restriction in the choice of sites for wells, which is due to the extreme dissection of the Carboniferous rocks in Britain, is in itself a very unfavourable factor. It limits the possible areas for drilling to a small percentage of the whole area, and localizes the wells on structures which, although themselves favourable, are merely subsidiary portions of larger structures that are distinctly unfavourable. The wells which are being put down in the Chesterfield area are situated on the axis of a sinuous anticline in the main Yorkshire basin; this anticline runs through Brimington in a northerly direction and then curves westward. Drilling operations are also in progress both in North Staffordshire and Midlothian.

The evidence which has been brought forward in favour of the possible occurrence of oil-pools in Great Britain may be considered under three heads:—

1. The indications of petroleum.
2. The supposed association of oil and carbonaceous strata.
3. The analogy with the American oilfields.

The writer proposes to describe and discuss this evidence in an endeavour to estimate the chances of success which await the present drilling operations.

1. Indications of Petroleum.

It is natural that prominence should be given to the evidence of asphalt, oil, and gas within the strata of these Islands by those who favour the present project. The occurrences are not uncommon, especially in the Carboniferous system, and apart from the pre-Cambrian and older Palæozoics, examples appear to have been noted almost throughout the geological column. The rare and local occurrences of bitumen in the pre-Carboniferous rocks of Britain, mainly in the Old Red Sandstone, are of no economic significance, and he would need be more than an optimist who drilled his wells within these formations. Throughout the Carboniferous system the evidence of hydrocarbons is more common. Instances of local oil impregnation in the strata of the Calciferous Sandstone series of the Lothians are probably due to destructive distillation of contiguous "oil-shale" by pyrometamorphism. This reaction is essentially similar to the present process of retorting the shale, and a corresponding

effect is often noticed in the Coal-Measures where igneous dykes and sills approach the carbonaceous material. The Carboniferous Limestone often contains dark bituminous impregnations and small patches of hard black asphalt, but the elaterite of the Castleton area is of doubtful significance. A boring at Norton, near Stockton-on-Tees, yielded a small show of oil from shales above the Carboniferous Limestone, and paraffin wax was noted from the same formation at Ladysmith Colliery, Whitehaven. The oil obtained from the Kelham boring near Newark appears to have come from the Millstone Grit series.

Among the Coal-Measures methane is, of course, a well-known material associated with coal-seams, but it is significant rather of a phase of vegetable decomposition than of any necessary association with petroleum. Sometimes this gas escapes at the surface, the old gas spring at Wigan described by Thomas Shirley in 1667 being an interesting example. Liquid petroleum has sometimes been recorded in mines, either as an oily impregnation of the shales or as a slight drip from the roof of a coal-seam. Such instances occur in most of the coalfields, but the quantities of oil are small. Occasionally larger yields have been obtained. At Meirhay Colliery, Longton, North Staffordshire, five tons of oil were produced and refined per week for several years, while the still better-known example at Southgate Colliery, Clowne, yielded about 300 gallons per week. This oil was refined by James Young in 1848, and when the supply ceased attempts were made to distil coal. These led to the retorting of torbanite and eventually to the foundation of the Scotch oil-shale industry. Occasionally oil escapes to the surface of the Coal-Measures, examples being found at Coalport and Pitchford in Shropshire. Still more rarely it impregnates an outcropping porous rock; the best example occurs at Coalbrookdale.

Both the Permian and the Trias have afforded a few examples of bitumen; oil from the Magnesian Limestone and gas from wells in the Trias. The Jurassic clays frequently contain a small amount of bituminous matter. The Calvert boring yielded gas from the Lias clays, while the gas from Heathfield, probably from the Upper Jurassic clays, was used for lighting the local railway station. Among the Cretaceous and Tertiary strata in Britain, evidences of bitumen are exceedingly rare.

Having briefly enumerated the main indications of bitumen in the British Isles, it will be necessary to discuss their significance. They may be generally summarized as small, even insignificant, and in the rare cases of a somewhat larger yield the supply was quite ephemeral. Now it is not generally realized that bitumen in small quantities is almost universally distributed in nature; even igneous rocks are not free from the material, and among the marine sediments it is quite common. Hence the mere enumeration of a long list of interesting but minute occurrences of asphalt, oil, and gas in a country like Great Britain, where geological exploration, quarrying, mining, and drilling have accumulated large stores of knowledge of the strata, can hardly be a matter of surprise. The significance of an oil show is not in the seepage itself, but in what it indicates. It

may mean nothing or it may mean everything. It is only of economic value when it is indicative of an underlying porous reservoir rock impregnated with petroleum.

A series of small shows of gas, oil, and asphalt, distributed haphazard in a thick mass of marine or deltaic sediments, with no consistency of geological horizons, and not associated with fault planes, can hardly be significant of an underground oil reservoir. The formation of hydrocarbons in small quantities is quite common in nature; it is the large accumulations which are more rare. If these small oil and gas shows were the result of gradual upward migration from a lower formation, it would be natural to expect that the movement would largely take place along the easiest planes of egress, i.e. faults, and porous strata. The extensive mining of the Coal-Measures would have given ample opportunity to illustrate this feature. Admittedly faults in softer strata tend to become sealed by a plastering effect, but even so they form easier avenues of passage than the undisturbed strata. The absence of any evidence of this upward migration along fracture planes, and the promiscuous distribution of the insignificant oil and gas shows, justify the assumption that they are in the main of local origin. In view of the fractured nature of the Carboniferous rocks, it is incredible that large supplies of oil could be held in the lower portions of these strata without giving abundant evidence of migration. The known tendency of these materials to take advantage of every shatter-plane, which is exemplified in all disturbed oilfields, is so characteristic that it may be taken as a general law.

But the question of the indications of oil is by no means exhausted. It has been previously noted that in the present search for oil, reliance is being placed largely on the possibility of oil occurring in the porous Millstone Grits or Carboniferous Limestone, where these are capped by impervious shales. If this assumption is true, it ought to be found that wherever there exist anticlines composed of these porous strata, wherein denudation is at present just stripping off the overlying impervious beds and revealing the crest of the underlying reservoir rock, the exposures of the latter ought to yield unmistakable evidence of an oil impregnation, even though most of the lighter oil may have been volatilized. Two excellent examples of such partially denuded domes occur at Ashover, and a few miles north-east of Leek. Both of these have been examined by the writer; neither of them yields evidence of oil impregnation beyond the insignificant amount usual to the Carboniferous elsewhere.

Thus it is seen that when the porous horizons of the Lower Carboniferous rocks are exposed in the cores of domes, there is no adequate oil impregnation or remains of such. Also, when these porous horizons are covered by impervious shales, there is no indication of oil migration such as would inevitably occur where the numerous fault-planes in the Coal-measures crossed the position of the underlying oil-pools. These two factors indicate that little or no value can be attached to the so-called indications of petroleum in Britain. These are merely insignificant examples of the universality of bitumen in minute quantities.

2. The supposed Association of Coal and Oil.

In Pennsylvania, Trinidad, Burma, Borneo, and elsewhere, it has been stated that the oil is found associated with coal or lignite. Those organic-origin theorists who believe that oil has been produced from terrestrial vegetation lay stress on this association of coal and oil, and infer that similar vegetable material entombed within the clays in the lower and more deeply buried strata have undergone a process of destructive distillation resulting in the production of liquid and gaseous hydrocarbons. It would be out of place to discuss the merits or demerits of this purely theoretical question. Suffice it to say that in the majority of the world's oilfields no such association of oil and coal exists, and in the cases noted above the line of demarcation between the oil and the coal-bearing strata is so well defined that the observer is impressed with the distinction between the two formations, rather than with their association. As far as the British Carboniferous strata are concerned, it is difficult to understand of what significance this supposed association can be in favouring the occurrence of underground oil-pools.

It has been stated by Mr. E. H. C. Craig that the oil-shale group of the Lower Carboniferous of the Lothians represents an old oilfield below the Carboniferous Limestone series with its contained coal-seams. The exact original form of the organic material which constitutes the oil-yielding portion of "oil-shale" is not at present known, but neither the chemical, microscopic, nor geological evidence can be brought into agreement with Mr. Craig's hypothesis. As far as the Lower Carboniferous rocks of Britain are concerned, to postulate that the coal-bearing measures will be succeeded at depth by oil-bearing strata on the grounds of a purely theoretical idea of oil formation, is to beg the whole question. The strata below the British Coal-Measures are a distinct and separate formation. The question whether they do or do not contain oil is a matter which must be settled by an examination of their own lithology and contents. The overlying Coal-Measures are only significant as a possible impervious cover rock to prevent the underlying oils from escaping.

3. The Analogy with the American Oilfields.

The two previous sections have really not touched the heart of the whole problem. Oil and gas fields have been discovered without any surface indications whatsoever by the mere process of trial and error, the lucky well of a "wild-cat" venture followed by the inevitable rush of oil prospectors, all eager to share in the gain. Indeed, it may be said that most of the American Palæozoic oilfields have been discovered in this way. Is it not therefore legitimate to assume that what is true of America may also prove true in this country? That, if deep wells are drilled so that the lower strata are thoroughly tested, and if in addition the sites of these wells are carefully chosen, it ought to be possible, or even probable, that similar supplies of oil and gas will be found. It is urged that England has not been thoroughly tested by deep wells, and until this is done no one can consider the matter as finally settled. In this section the writer will

endeavour to compare the geological conditions in Britain with those of the American oilfields, with a view to discovering whether these conditions are sufficiently similar to warrant the assumptions which have just been stated.

Before proceeding with the comparison it will be necessary to make a few preliminary statements on the general geological occurrence of petroleum in the world. In the first place, the oilfields may be divided into two main groups—those of Upper Cretaceous and Tertiary age, and those of Palæozoic age. This somewhat sweeping assertion overlooks a few small fields in Europe and America, but is in the main correct. The Upper Cretaceous and Tertiary fields form a belt encircling the world: Galicia, Rumania, Caucasus, Persia, Burma, Sumatra, Java, Borneo, Japan, California, the West Indies, and Peru. In all these fields the strata are in the main strongly folded, often faulted, and sometimes thrust. Usually surface indications of asphalt, oil, and gas are numerous, and productive wells are largely located on the anticlinal folds.

The Cretaceous–Tertiary fields of Mexico, the Gulf States, and Alberta are exceptions to this general assertion; the structures are not folded to the same extent and usually the surface indications are not so numerous. The Palæozoic oilfields on the other hand are at present completely confined to North America, and particularly to the United States. The more important oilfields range in age from the Upper Ordovician to the Pennsylvanian, most of the oil being found in the Devonian, Mississippian, and Pennsylvanian. As contrasted with the Tertiary oilfields, the older fields do not occur on belts of mountain-building movement. They are not even affected by well-defined folds, but occur on broad open undulations with such gentle dips that the structures would not be apparent on sections drawn to scale. The oil-pools are situated on terraces, minor flexures, and gently dipping sand-lenses. To speak of these minor flexures as anticlines and synclines tends to give a wholly exaggerated idea of their importance, for the dips rarely exceed 2°, and are usually only from 20 to 50 feet in the mile. As a general rule surface indications of petroleum are rare in these fields. Asphaltic sandstones are found in Oklahoma and Texas, and oil and gas seepages to a small extent in Western Pennsylvania and New York State, but such occurrences are infinitesimally small compared with the immense supplies of oil and gas which are found underground.

Now there is no peculiar significance in geological age which would lead us to infer that all new oilfields will necessarily conform in their stratigraphical position to those at present known. Yet there are distinct lithological portions of the crust where it would be futile to search for petroleum, i.e. the pre-Cambrian and the British Trias. The strongly folded and deeply dissected Lower Palæozoics, the Old Red Sandstone, the Mesozoics, and the Tertiaries of Britain are all for varying reasons ruled out as possible strata containing oil-pools. There remains the Carboniferous system, the strata of which have yielded the most abundant signs of bitumen, and which have been more extensively mined than any others in the geological column.

If it is expected that the British Carboniferous strata will contain underground oil-pools, it will be legitimate to assert that the same general laws which are found essential for the occurrence of oil-pools in the American Palæozoic fields, ought to be applicable with the same force to the Carboniferous strata in Britain. It will then be advisable to examine the general tectonics of the American Palæozoic fields in order to discover the structural laws governing the occurrence of the oil, and afterwards to apply these laws to our own Upper Palæozoics in Britain.

The Pennsylvanian oil and gas fields will be taken as a typical area which has been thoroughly tested with the drill, and which, moreover, can be readily studied by means of the excellent maps and reports published by the United States Geological Survey. The structure of these fields is in the main a broad flat geosyncline of Devonian and Carboniferous rocks bordering the western edge of the Pennsylvanian Mountains. The beds are entirely devoid of true folding, but are warped into an alternating series of structural terraces or curved into a succession of extremely gentle undulations. These sinuous undulations are termed anticlines and synclines, but it must be remembered that their dips are usually only from 20 to 50 feet in the mile and seldom approach 2°.

The structures throughout the oil and gas field belt are all of this gently undulating, almost horizontal type. It is significant that where the productive zone approaches the real zone of folding on the east, where the sinuous broad undulations are replaced by definite anticlines and synclines with dips of 5° and upwards, the oil and gas suddenly disappear, though the same strata still persist in this outer belt of folded rocks. Thus in S.W. Pennsylvania the gas anticline of Belle Vernon is succeeded on the east by the Brownsville anticline with a small oil and gas field at its southern extremity. Both these structures are merely gentle undulations with dips below 1°. The succeeding anticline on the east, the Favette anticline, is a definite fold structure with dips of 3° to 4°. Here the prolific oil and gas zone has almost completely disappeared, and only a few gas wells of small yield lie on this otherwise completely barren anticline. Still further east no oil or gas has been discovered.

This sudden impoverishment of the strata takes place within a distance of 5 to 10 miles, and it can be traced longitudinally along the border of the folded zone for over 100 miles. The position which marks the eastern limit of the main oil and gas fields is found in every case to coincide with the first anticline where the dips approach or exceed 3° to 4°.

It may be objected that these statements are a direct negation of the well-established theory of the anticlinal occurrence of oil, a theory which has proved its value all the world over. In spite of the recent tendency in oil technology to overestimate the importance of this idea, there is no doubt that it constitutes one of the fundamental principles of oil concentration. It is not suggested by the writer that the oil in Tertiary fields cannot and does not occur in strongly developed anticlinal folds, but it is asserted that the productive fold structures of the American

Palæozoic fields are of an entirely different type. They are mere broad undulations of the strata associated with epeirogenic movements, and differ essentially from the folds immediately associated with orogenesis. Pennsylvania has been chosen merely as a good example of structures which are typical of all the American Palæozoic oil-fields, with perhaps the single exception of Southern Oklahoma and North Texas, which will be alluded to later.

The characteristic association of oil with relatively undisturbed strata in the American Palæozoic oilfields has been emphasized by David White in a general law which he has formulated that "In regions where the progressive devolatilisation of the organic deposits in any formation has passed a certain point, marked in most Provinces by 65 to 70 per cent of fixed carbon (pure coal basis) in the associated or overlying coals, commercial oil-pools are not present in that formation nor in any other formation normally underlying it, though commercial gas-pools may occur in a border zone of higher carbonization".[1]

The exact relationship of the composition of coals to earth stresses is a disputed point, but it is certain that if White's law holds good, and it is the result of wide experience in American fields, it effectively eliminates the possibility of oil being found below most of the British Coal-Measures.

The fundamental truth which is contained in this generalization appears to the writer to be largely concerned with the last of the three necessary conditions for the formation of a commercial oil-pool:—

1. The formation of the oil.
2. Its migration to suitable porous reservoir rocks.
3. Its preservation from seepage and denudation by a thick cover of impervious strata.

The formation of the oil entails the entombment of organic matter under marine anærobic conditions, and probably includes certain biochemical changes resulting in the production of hydrocarbons.

The migration of the oil probably results from the compacting of the sediment, the pressing out of the oil and salt water from the compressible argillaceous sediments into and through the sandy and dolomitic horizons whose spore space is not materially reduced by pressure.

With regard to the third essential, the rapid seepage of oil and gas in the folded Tertiary oilfields teaches us how quickly such material can be lost from the strata, and it is obvious that the most important factor in the preservation of oil over long geological periods is the effectiveness with which it is sealed by the overlying impervious rocks. This essential implies the absence of strong folding, important fracturing, and deep dissection of the strata. Where this is not the case, the resultant migration during long geological periods has been sufficient to allow complete loss of the volatile gas and fluid from the oil reservoirs below. The same tendency is of course true of the Tertiary oilfields; the process of

[1] Journ. Wash. Acad. Sci., vol. v, p. 212, 1915.

loss by evaporation and seepage is going on in them at the present time, but the geological time has been insufficient for complete leakage, being relatively short compared with the long geological periods of post-Carboniferous history.

An interesting and instructive example of the great importance of migration in disturbed strata is afforded by the Palæozoic oilfields of Southern Oklahoma and Northern Texas. The oil is found mainly in strata of Permian age, the so-called "red beds". These rocks are tilted at angles somewhat greater than is usual in Pennsylvania, and they are underlain unconformably by strongly disturbed Carboniferous strata. There are two interesting features about the oil occurrence in these fields to which attention is here directed. Firstly, the common occurrence of asphaltic sandstones in surface outcrops indicating the petroliferous nature of the underlying strata. Secondly, the almost certain conclusion that the oil is not indigenous in the Permian formation, but has migrated upwards from the disturbed Carboniferous strata. During this migration some of the oil has evidently escaped to the surface, hence the asphaltic sandstones, but the great thickness of the Permian cover-rock, probably helped by overlying Cretaceous and Tertiary beds now removed, retained large portions of the oil in the strata.

These features serve to illustrate the two main facts on which stress is laid in the present communication :—

1. That disturbed strata, especially when strongly faulted, do not easily retain oil over long geological periods owing to the leakage of this somewhat elusive material to the surface.

2. That when such migration has taken place, or is taking place, the indications of bitumen in the overlying rocks or at the surface are sufficiently obvious to leave no doubt in the mind of the investigator as to the petroleum content of the underlying strata.

The writer must apologize for a long digression into the occurrence of petroleum in the American Palæozoic rocks, but such a comparison is necessary seeing that it is among the British Palæozoics that the search for oil is at present being carried out. The same laws which are necessary for the preservation of oil in the one country should hold good in the other, and the folding, fracturing, and subsequent denudation of the British Carboniferous strata should be compared with that of the same strata in the American oilfields. This comparison will indicate whether it is possible or likely that large quantities of oil still remain in the Carboniferous strata of these Islands.

It will be noticed that the writer is assuming that the first two essentials, the formation of the oil and its migration to suitable porous reservoirs, have been fulfilled in the case of the British rocks. Such an assumption may in itself be illegitimate, for oil formation on a large scale requires special geological conditions. Whether these conditions were fulfilled during the deposition of any of the sedimentary formations in the British Isles must be largely a matter of opinion, but it is quite probable that such has been the case. Apart from the Carboniferous rocks in the South of England, Wales, and Ireland, these strata elsewhere escaped the

main thrust of the American mountain-building movements. In spite of this they have been folded, tilted, and fractured to an extent which can be readily gauged by the inspection of any of the Coal-Measure maps. In addition, the subsequent denudation has been so extensive that the lower rocks are exposed in the anticlinal areas and the Coal-Measures are largely confined to the structural basins. It is largely in the subsidiary upwarps of these synclinal areas that the borings for oil are situated. The tilting and faulting of the Coal-Measures, small as it may be when compared with the structures in the main mountain zones, is much more intense than in any of the American Palæozoic oilfields. In view of this difference in tectonics, and still further the extreme erosion to which Palæozoic rocks have been subjected in these Islands, the chances of finding commercial supplies of petroleum are extremely small. To be sure there is hardly any doubt that small quantities of oil and gas lie locked up within the impervious strata of Britain; such patches have been found before and no doubt will be found again, but they will give little satisfaction to those who believe the country is yet to be covered with flourishing oilfields.

The comparison of Britain and America is an unfortunate one. The broad area of American Palæozoic rocks, between the Pennsylvanian Mountains on the east and the Rocky Mountains on the west, lies on the great Pre-Cambrian shield of North America, and, though bordered by mountains, it has never been affected by orogenic movements. On the other hand, the structure of Britain may be said to be based on mountain-building movements. Pre-Cambrian, Caledonian, and Armorican movements have successively striven to impose their structures on the ground-plan of these Islands. The folded, crumpled, and rifted nature of our Palæozoic structures testify to the success of their efforts. Even the Alpine folds invaded our southern shores. To search for petroleum in such structures, deeply dissected by extensive periods of denudation, cannot be justified by comparison with any analogous examples of successful oilfields in the equivalent formations of the rest of the world.

Conclusions.

It appears to the writer, after a review of the oil indications and comparison of the geological conditions both in Britain and America, that the following conclusions may be drawn:—

1. The asphalt, oil, and gas occurrences in Britain are no more than would be expected in any thick mass of deltaic and marine sediments. Their haphazard distribution indicates their local origin and does not imply any association with commercial oil-pools.

2. There is a significant absence of definite oil and asphalt indications in localities where the geological conditions would lead one to expect such occurrences, on the assumption that the Lower Carboniferous rocks contain large supplies of oil.

3. No parallel can be drawn between the structures of the British Carboniferous rocks and the equivalent formations of the American oilfields. The structures in the British formations are much more highly warped and fractured than are those in America.

Furthermore, their denudation is so extensive that the possibility of preservation of large oil-pools in such fractured rocks which have suffered such deep dissection is unlikely in the extreme.

4. Small quantities of oil and gas locally preserved among the impervious strata are both possible and probable. Such occurrences, however, are too small to be of commercial importance.

On May 27 an oil-show was struck at the Government boring at Hardstoft, near Chesterfield, at a depth of about 3,075 feet. The oil is stated to have risen slowly in the well and finally overflowed, yielding about 400 gallons a day. It appears to have come from the compact limestones and shales at the base of the Yoredale Series, and the absence of porosity in these strata limits the hope of a large commercial supply of petroleum. The character of the seepage in the well tends to confirm the impression of a slow outflow from relatively compact rocks. It was presumed, somewhat hastily, that the Hardstoft oil-show was indicative of a large oil supply which would be tapped when the cover-rock had been completely pierced, but the resumed drilling operations have so far negatived this assumption. Similar oil seepages are quite likely to occur in some of the other bores at the same geological horizon, but the statements which have been assiduously circulated that the discovery at Hardstoft proves the existence of large quantities of crude petroleum in these Islands, betray a complete inability to estimate such occurrences in their true proportion.

In the discussion of a problem where political, economic, public, and scientific interests are deeply involved, it is difficult to avoid the clash of warring elements. The writer wishes to emphasize the fact that the present discussion is entirely concerned with the possibilities of success. Whether the present oil development operations were justifiable in view of the urgency of the war needs, is a question rather of political responsibility and is entirely beyond the scope of the present paper.

That a large sum of money could be well spent on boring in this country is undoubtedly true—the survey of our natural wealth is inadequate without it—but why confine the search to oil, one of the most improbable materials, if scientific evidence stands for aught? The data afforded by the percussion method of drilling are very unsatisfactory, especially when the sampling is left in the hands of the driller. Core drills are more slow, but the scientific evidence obtained is incomparably greater. It is true that small oil-shows would possibly be overlooked in core drilling, but this difficulty is not insuperable, and in addition the type of oil-well which will alone repay the cost of such deep wells as are anticipated would leave no doubt of its occurrence. In the Chesterfield area, where operations are now in progress, little additional knowledge could be obtained of the beds in association with the Black Shale coal, but a series of cores in the underlying strata would yield useful and possibly valuable data. It is to be deplored that by a system of haste where no haste is now necessary, and where the possibilities of success are extremely doubtful, an opportunity should be thrown away of getting valuable evidence which would possible repay the public expenditure.

II.—On the Stafford Earthquakes of January 14–15, 1916, and on the Relations between the Twin-Earthquakes of the Midland Counties.

By Charles Davison, Sc.D., F.G.S.

THE strong shock of January 14, 1919, originated in a region from which earthquakes have been absent for many years, perhaps for several centuries, and its interest is therefore increased by the fact that it was a twin-earthquake, that is, one produced by a single generative effort in two detached foci.

There is no certain evidence of any fore-shock, and, so far as I know, there was only one after-shock.

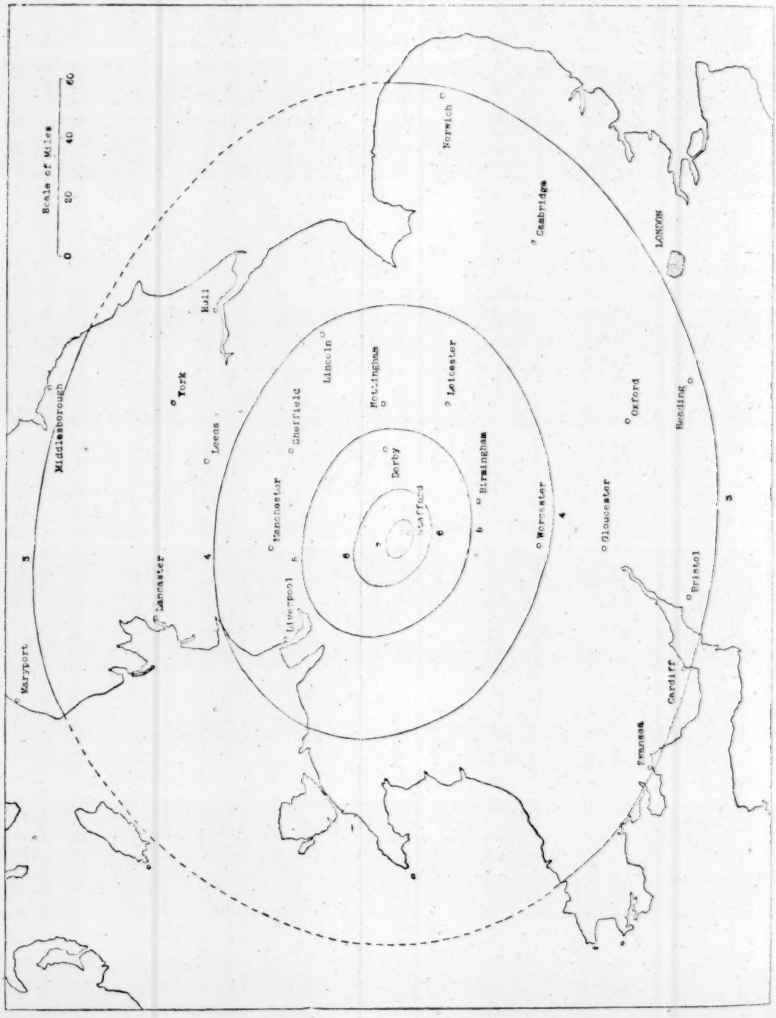


FIG. 1.

Principal Earthquake of January 14, 1916.

Time of occurrence, 7.29 p.m.; intensity, 7; centre of isoseismal 7 in lat. 52° 52′ N., long 2° 9′ W.; number of records, 1241, from 580 places.

Time of Occurrence.

The time of occurrence is determined with unusual precision. The first tremors were recorded at West Bromwich, as Mr. J. J. Shaw kindly informs me, at 7 h. 29 m. 6 s. p.m. At Birmingham I felt the shock at 7 h. 29½ m. The average of seventy-four estimates of the time, which, according to their observers, are accurate to the nearest minute, is 7 h. 29 m. As these observers were all within the isoseismal 4, it is probable that the time at the epicentre must have been 7.29 p.m., or possibly a few seconds earlier.

Isoseismal Lines and Disturbed Area.

On the map of the earthquake (Fig. 1) are shown five isoseismal lines corresponding to intensities 7–3 of the Rossi-Forel scale, or rather of that form of the scale which I have employed in studying British earthquakes,[1] the two inner isoseismals being represented on a larger scale in Fig. 2. With regard to all the isoseismal lines, except the innermost, it should be mentioned that the comparative scarcity of observations in the western district does not admit of great accuracy in tracing the lines there. The true course of each line may vary by a mile or more, and in the outermost line by several miles, from that laid down on the map. The inaccuracy, if it exists, is not, however, of much consequence.

The dimensions of the isoseismal lines are given in the following table:—

Isos.	Length, miles.	Width, miles.	Area, sq. miles.	Direction of longer axis.
7	12½	9	88	E. 22° S.
6	32½	25	637	E. 28° S.
5	68	55	2,908	...
4	144	112	12,500	...
3	281	225	50,200	...

The centre of the isoseismal 7 is in lat. 52° 52′ N., long 2° 9′ W., or 2 miles S.S.W. of Stone. The distances between the isoseismals 7 and 6, 6 and 5, 5 and 4, are respectively 9½, 18, and 32 miles on the north side, and 5, 12½, and 12 miles on the south side.

Outside the isoseismal 3, the shock was probably felt at Maryport, 14 miles from the line. Excluding this exceptional observation, the area disturbed by the earthquake is about 50,200 square miles.

If we measure the relative strength of British earthquakes by the area enclosed within the isoseismal 4—for the isoseismal 3 cannot always be drawn—the Stafford earthquake occupies the seventh

[1] *Geogr. Journ.*, vol. xlvi, pp. 360–1, 1915.

place among the earthquakes of the last thirty years, the areas for the ten strongest earthquakes being given in the following table :—

Earthquake.	Area of Isos. 4, in sq. miles.
Hereford, 1896	98,000
Pembroke, 1892	44,800
Swansea, 1906	37,800
Pembroke, 1893	35,900
Inverness, 1901	33,000
Carnarvon, 1903	19,500 (about)
Stafford, 1916	12,500
Derby, 1903	12,000
Doncaster, 1905	10,700
Derby, 1904	10,120

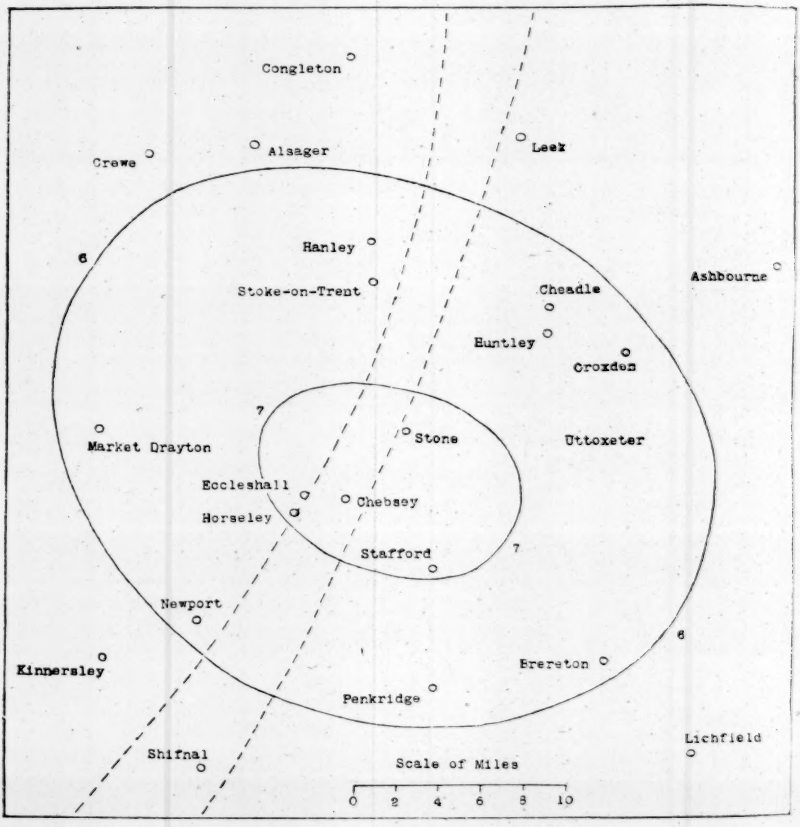


FIG. 2.

It is remarkable that all these earthquakes, with two exceptions (the Inverness and Carnarvon earthquakes) belong to the class of twin-earthquakes.

Nature of the Shock.

The following accounts may be regarded as typical of the nature of the shock in different parts of the disturbed area (see Fig. 2):—

(1) Chebsey: the shock consisted of one series of vibrations accompanied by sound which increased in strength to a maximum and then died away.

(2) Coton Hill (near Stone): the shock consisted of one continuous series of vibrations, lasting about six seconds, increasing in strength from the beginning and dying away towards the end; in the middle, there were two maxima separated by about half a second.

(3) Brereton: the shock was in two distinct parts, the first being the stronger, and the interval between the two series being two or three seconds.

(4) Kinnersley: the shock was again in two distinct parts, separated by an interval of two seconds, the second part being the stronger.

Over the greater part of the disturbed area, and in some directions even as far as the isoseismal 3, the shock consisted of two distinct parts. Thus, the wide distribution of the places at which the double shock was felt precludes the supposition that the earthquake was caused by a single impulse, the resulting waves of which were duplicated by reflection or refraction. Nor can the two parts of the shock represent direct and transverse vibrations resulting from a single impulse; for, as will be seen later, the duration of the interval between the two parts does not increase with the distance from the origin. Nor, lastly, could the two parts be caused by successive impulses in the same focus; for, if this were the case, there could be no part of the disturbed area in which the two series of vibrations coalesce. We are thus led to conclude that the two parts of the shock were derived from distinct impulses originating in different foci.

When the places are mapped at which the double and single shocks were felt, we find that the former are absent from a band which crosses the isoseismal 7 at right angles to its longer axis at a short distance to the west of the centre. The band is very slightly curved, the concavity facing the west. Within this band (as at Chebsey), the shock was either single or consisted of one series of vibrations with two maxima. Close to the band (as at Coton Hill, one mile to the east), and on either side of it, the shock was single with two maxima. At many places the observers differed, some regarding the shock as single, others as double. For instance, at Hanley and Stoke-on-Trent, which lie one mile to the west of the band, fifteen observers regarded the shock as single and five as double. At places farther from the band, such as Brereton (13 miles) and Kinnersley (4 miles), the two parts were entirely distinct.

It is clear, from the above account, that the two series of vibrations were felt practically in all parts of the disturbed area, but that in the curvilinear band, the two series were felt simultaneously and so appeared as a single shock either with one maximum or two maxima close together. On this account, the band is known as the synkinetic band.

The existence of this band is evidence that the impulses in the two foci occurred so closely together that the second focus was in action before the vibrations from the first focus had time to reach it. When the two impulses are simultaneous, the synkinetic band is straight and crosses the axis of the central isoseismal at right angles through its middle point. This was the case in the Derby earthquake of 1903. If one impulse were to occur a second or so before the other, then the waves from the focus first in action would travel farther than the waves from the other focus before the two series of vibrations coalesced. That is to say, the synkinetic band would be slightly curved, it would pass nearer to the focus last in action than to the other, and its convexity would be turned towards the focus at which the first impulse occurred. From the form of the synkinetic band, as shown by the broken lines in the map, we conclude that the two impulses which formed the Stafford earthquake occurred almost simultaneously, but that the eastern focus was in action very slightly—perhaps a second or two—before the western focus.

That the two impulses were very nearly equal in strength is clear from the wide observation of the double shock. If they had differed greatly in intensity, only the stronger part would have been felt near the boundary of the disturbed area. This approximate equality is also indicated by the observations on the relative intensity of the two parts of the shock. For instance, in Staffordshire and the adjoining counties of Shropshire and Derbyshire, on the east side of the synkinetic band, 25 persons regarded the first part, and 20 persons the second part, as the stronger; on the west side of the band, 21 persons regarded the first part, and 27 the second part, as the stronger. Thus, it seems probable that, though the two impulses were nearly equal, that of the eastern focus was slightly stronger than that of the other.

The synkinetic band has only been traced for four earthquakes. In the Derby earthquake of 1903, the impulses were simultaneous and practically equal in strength. In the Hereford earthquake of 1896, the Derby earthquake of 1904, and the Stafford earthquake of 1916, the foci were in action not quite simultaneously, and the impulses were unequal in strength.

The duration of the shock was estimated with care by 198 observers, and that of the interval between the two parts by 107 observers. The average of the former estimates is 3·1 seconds, and of the latter 2·2 seconds. The figures in the following table (p. 307) show how these averages vary with the distance from the origin.

It should be mentioned that, in determining the average duration of the shock, estimates when one part only was observed are included.

District.	Average Duration.	
	Shock, secs.	Interval, secs.
Within isoseismal 7	4·0	2·0
Between ,, 7 and 6	4·0	2·1
,, ,, 6 ,, 5	3·2	2·4
,, ,, 5 ,, 4	2·4	2·4
,, ,, 4 ,, 3	2·5	1·1

Sound-Phenomena.

Sound-Area.—The boundary of the sound-area is represented on the map of the earthquake by the dotted line. This lies between the isoseismals 4 and 3, and includes an area 177 miles long, 157 miles wide, and containing about 21,000 square miles.

Within the whole area, the sound was heard by 77 per cent of the observers. The decline in audibility, as the sound-waves progressed outwards, follows the same law as in other strong earthquakes, being 98 per cent within the isoseismal 7, 96 per cent between the isoseismals 7 and 6, 83 per cent between the isoseismals 6 and 5, 57 per cent between the isoseismals 5 and 4, and 31 per cent outside the last isoseismal. For the Derby earthquake of 1904, which closely resembles the Stafford earthquake, the corresponding percentages are 94, 93, 79, 56, and 38.

Nature of the Sound.—The sound is described by 663 observers. In 53 per cent of their records the sound is compared to passing traction-engines, motor-cars, etc., in 7 per cent to thunder, in 9 to wind, in 8 to loads of stones falling, in 9 to the fall of a heavy body, in 12 to explosions, and in 2 per cent to miscellaneous sounds.

The variation in the nature of the sound with the distance from the epicentre is shown in the following table, in which the figures are percentages of comparison to the different types for each of the districts mentioned :—

District.	Passing vehicles.	Thunder.	Wind.	Loads of stones falling.	Fall of heavy body.	Explosions.	Miscellaneous.
Within isoseismal 7	35	10	2	11	17	23	2
Between ,, 7 and 6	46	7	9	9	13	14	2
,, ,, 6 ,, 5	61	5	9	8	6	9	2
,, ,, 5 ,, 4	47	14	10	5	8	13	3
Outside ,, 4	46	15	15	8	0	15	0

Omitting the references to miscellaneous sounds, the types of passing vehicles, thunder and wind are of long, and the others of short, duration. The percentages of reference to types of long

duration for the above districts are respectively 47, 64, 77, 73, and 77; showing that as the distance increases from the origin, the sound becomes smoother and more monotonous. This is especially noticeable in the case of references to the third type, that of wind.

Time-Relations of the Sound and Shock.—In the following table the figures under the letters p, c, and f indicate the number of records per cent in which the beginning or end of the sound preceded, coincided with, or followed, the corresponding epoch of the shock; and those under the letters g, e, and l show the number of records per cent in which the duration of the sound was greater than, equal to, or less than, that of the shock:—

District.	Beginning.			End.			Relative Duration.		
	p	c	f	p	c	f	g	e	l
Within isoseismal 7	56	26	18	8	71	21	58	42	0
Between ,, 7 and 6	63	29	8	33	35	32	58	42	0
,, ,, 6 ,, 5	58	38	4	21	60	19	56	35	9
,, ,, 5 ,, 4	63	12	25	...	...	...	...	...	...
Whole sound-area	60	32	8	25	51	24	57	38	5

It will be seen that the percentages for the beginning and end lend no support to the view, sometimes expressed on insufficient observations, that the sound travels more rapidly than the waves which form the shock. Had this been the case, the figures for the precedence of the sound would have shown a very rapid increase with the distance from the origin.

After-Shock: January 15.

Time of occurrence, 10.45 a.m.; intensity, 4; number of records, 7, from 7 places.

A slight shock was felt at Alsager, Cheadle, Coton Hill (near Stone), Croxden (near Uttoxeter), Horseley (near Eccleshall), Huntley (near Cheadle), and Stone. With one exception, these places lie within the isoseismal 6 of the principal earthquake (Fig. 2). Alsager lies one mile to the north. From the distribution of these places, it seems probable that the epicentre is not far from the centre of the isoseismal referred to, and therefore lies between the two epicentres of the principal earthquake. The shock was a slight one, and consisted of a single series of vibrations.

Origin of the Earthquakes.

From the forms and relative positions of the isoseismal lines, we obtain the following elements of the originating fault: (1) its mean direction lies between E. 22° S. and E. 28° S., or about E. 25° S.; (2) its hade is to the north; and (3) the fault-line must pass within a short distance (about a mile or two) on the south side of the centre of the isoseismal 7. This position for the fault-line is, however, given on the supposition that the fault-surface is a plane. If the

surface were curved and increasing in inclination to the horizon as it approached the surface of the earth, the position above given would be the line in which a tangent-plane at the depth of the focus to the fault-surface meets the surface of the earth, and this ought to lie some distance to the south of the actual fault-line.

This apparent displacement of the presumed fault-line is specially characteristic of deep-seated earthquakes. In British earthquakes, the only test that we possess of the greater or less depth of the seismic foci is the less or greater rate of decline in the intensity of the shock at the surface. A rough test of this rate of decline is the area enclosed within the isoseismal 4 for shocks of different intensity at the epicentre. For earthquakes of intensity 7, this average is 22,000 square miles in England and Wales, and less than 4,000 square miles in Scotland; for those of intensity 5, the corresponding figures are 780 and 450. Thus, the rate of decline of intensity outwards from the epicentre is much more rapid in Scotland than in England; and this implies that the average depth of focus is much less in Scotland than in England and Wales. Now, Scottish earthquakes which cannot be correlated with known faults are very rare. In English and Welsh earthquakes it is quite an exception to be able to associate an earthquake with a known fault; and, in the few cases in which this is possible, the area within the isoseismal 4 is always small. It is therefore not surprising if we cannot point to any definite fault in the case of the Stafford earthquake.[1] Should we not rather look on the results of the earthquake investigation as adding to our knowledge of the structure of the crust at a depth which is far beyond the range of the field-geologist's methods?

Returning to the Stafford earthquake, the positions of the two epicentres cannot be determined with accuracy, but, from the form of the isoseismal 7 and the course of the synkinetic band (which must pass between the epicentres), it follows that the eastern epicentre must lie about two miles north-east of Stafford and the western epicentre about twelve miles north-west of Eccleshall. The distance between the epicentres would thus be about 8 or 9 miles, which differs little from the average (10 or 11 miles) for British twin-earthquakes.

For very many years, possibly for centuries, there has been no perceptible movement along the earthquake fault. Then, suddenly, two earthquakes occurred so closely together that the later could not possibly be a consequence of the earlier, for it took place before the earth-waves had time to traverse the interfocal region. The only movement that could produce such practically simultaneous displacements is one of rotation. We may conceive the earthquake-fault as cutting transversely a crust-fold (Fig. 3) the crest C and trough T of which are separated by a distance of about nine miles. If a small step took place in the growth of the fold, that is, if the

[1] Close to Eccleshall there is a small post-Triassic fault (Geol. Surv. map, sheet 22, S.W.), which is parallel to the longer axis of the isoseismal 7, and hades to the north. If this fault were continued to the east it would occupy the position assigned to the fault-line by the seismic evidence.

crest and trough were to become more pronounced, simultaneous movements of the fold—the crest C to C′ and the trough T to T′—would occur, and these movements would be accompanied by a rotation of the median limb, the central portion M of which would undergo no displacement. Thus, we should have two foci, CC′ and TT′, entirely separated by the interfocal region about M. Moreover, the forces which give rise to an earthquake of this kind must act at right angles to the direction of the fold, that is, parallel to the direction of the fault.

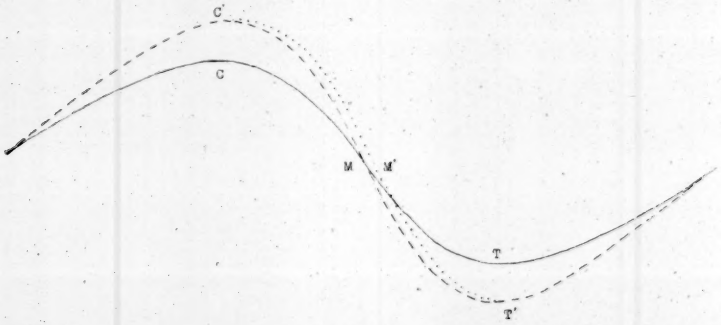


FIG. 3.

It is evident that movements of this kind would suddenly increase the stress within the median limb, and the effect of this increase would be a sudden movement of translation of the median limb into some such position as that indicated by the line C′M′T′, thus giving rise to a simple shock with its epicentre in the interfocal region of the twin-earthquake. The interval between the twin-earthquake and its first after-shock varies from a few hours to several weeks. In the Stafford earthquake, the observations of the after-shock are insufficient to determine its epicentre with precision; but it was probably due to a translation of the median limb of the fold about fifteen hours after the occurrence of the twin-earthquake.

ON THE RELATIONS BETWEEN THE STAFFORD EARTHQUAKE OF 1916, THE DERBY EARTHQUAKES OF 1903, 1904, AND 1906, AND THE LEICESTER EARTHQUAKES OF 1893 AND 1904.

On March 24, 1903, a strong twin-earthquake occurred in Derbyshire,[1] one focus being near Ashbourne and the other about 3 miles west of Wirksworth. The distance between the foci is thus about 8 or 9 miles, and the direction of the longer axis of the isoseismal 7 is N. 33° E. This earthquake was followed on May 3 by an interfocal after-shock, the direction of the longer axis of the isoseismal 5 being N. 25° E. On July 3, 1904,[2] another strong twin-earthquake occurred, in which the same foci were in action, the southern focus being 1½ miles east of Ashbourne, and the northern probably in the same position as in 1903. The

[1] Quart. Journ. Geol. Soc., vol. lx, pp. 215–32, 1904.
[2] Quart. Journ. Geol. Soc., vol. lxi, pp. 8–17, 1905.

distance between the foci is 6 or 7 miles, and the direction of the longer axis of the isoseismal 6 is N. 31° E. Eight hours later, on the same day, the earthquake was followed by an interfocal after-shock, the direction of the longer axis of the isoseismal 4 being N. 27° E. Lastly, on August 27, 1906,[1] a much slighter twin-earthquake occurred in the same foci as the earthquake of 1904, the direction of the longer axis of the isoseismal 5 being N. 25° E. The mean direction of the earthquake fault is thus about N. 28° E., which is nearly, but not quite, at right angles to that of the Stafford earthquake fault.

Again, on August 4, 1893,[2] a twin-earthquake of intensity 5 occurred in Leicestershire. The principal epicentre lies 2 miles S.S.W. of Loughborough, and the direction of the longer axis of the isoseismal 5 (which surrounds this epicentre only) is E. 30° S. The second epicentre lies close to the village of Tugby, and is 17 miles E. 34° S. of the other. There can be little doubt that both impulses originated along a single fault, the direction of which at the north-west end is E. 30° S., and at the south-east end about E. 40° S. A later earthquake, which occurred on June 21, 1904, in the south-eastern focus only, shows that the direction of the fault there is E. 42° S.

Now, if the fault-lines of the Stafford and Derby earthquakes be produced to meet, their point of intersection is 9 miles from the eastern focus of the Stafford earthquake and 18 miles from the southern focus of the Derby earthquakes. In both earthquakes, the distance between the foci is 8 or 9 miles, which is therefore the distance between the crest and trough of a crust-fold. Thus, the point of intersection of the two fault-lines is at a distance of half a crust-fold-length from the nearer focus of the Stafford earthquake, and of a whole crust-fold-length from the nearer focus of the Derby earthquakes. Also, if the fault-lines of the Derby earthquakes and of the Leicester earthquake of 1893 be produced to meet, their point of intersection is about 10 miles from the other point of intersection, about 8 miles from the southern focus of the Derby earthquakes (that is, about half a crust-fold-length from either), and about 26 miles from the north-western focus of the Leicester earthquake and 43 miles from its south-eastern focus (that is, about three and five half crust-fold-lengths from the two foci).[3]

If we may assume that the earthquake-faults are at right angles to the folds, to the growth of which the earthquakes are due, it would seem that the crust at a depth of a few miles below the counties of Stafford, Derby, and Leicester, is corrugated in two systems of folds approximately at right angles, and that the axes of the north-and-south folds exhibit a fan-shaped arrangement or

[1] GEOL. MAG., Vol. V, pp. 301-3, 1908.

[2] Quart. Journ. Geol. Soc., vol. lxi, pp. 1-7, 1905.

[3] It will be noticed that the distance between the foci of the Leicester earthquake is about double that between the foci of the Derby and Stafford earthquakes. Possibly, the foci of the Leicester earthquake occupy the crests of successive folds; but there are difficulties in the way of such an explanation.

continued easterly twist in successive lines, the direction being about N. 25° E. through the Stafford foci, N. 28° E. through the Derby foci, and N. 30° E. and N. 42° E. through the Leicester foci.

The existence of this deep-seated double system of corrugations may perhaps explain another peculiarity of British earthquakes. Dividing them into three classes of strong, moderate, and slight earthquakes, according as the areas embraced by the isoseismal 4 are greater than 5,000, between 5,000 and 1,000 or less than 1,000, square miles, it appears that the average length of focus for strong earthquakes is 12¼ miles, and for moderate, earthquakes 13 miles. Slight earthquakes are divisible into two groups, in one of which the focus is 9 miles or more in length, and in the other 6 miles or less in length. The average length of focus for the former is 12 miles, and for the latter (omitting a large number of very slight shocks) 4¼ miles. If we leave out of account the second division of slight shocks, which are of the nature of local creeps, it follows that the average length of focus in all three classes of earthquakes is very nearly the same, about 12½ miles.[1]

III.—The Late Glacial Gravels of the Vale of Edeyrnion, Corwen, North Wales.

By Bernard Smith, M.A., F.G.S.

(WITH A MAP.)

THE Corwen gravels were described by D. Mackintosh, forty-three years ago, in a paper "On the mode of Occurrence and Distribution of Beds of Drifted Coal near Corwen, North Wales".[2] He attributed the gravels to an interglacial marine submergence and claimed that the coal found in them was derived from the outcrop of Coal-measures near Ruabon, twelve miles due east of Corwen.

In the present communication a correlation is made between the Corwen gravels and certain gravels of Late Glacial age formed during the melting stages of the North Welsh valley glaciers. A brief description of these gravels, as a preface to our correlation, seems advisable in view of the fact that no general account of them has been published.

Reasons are given for assuming that the drifted coal, found at Corwen, was derived from a local concealed outcrop.

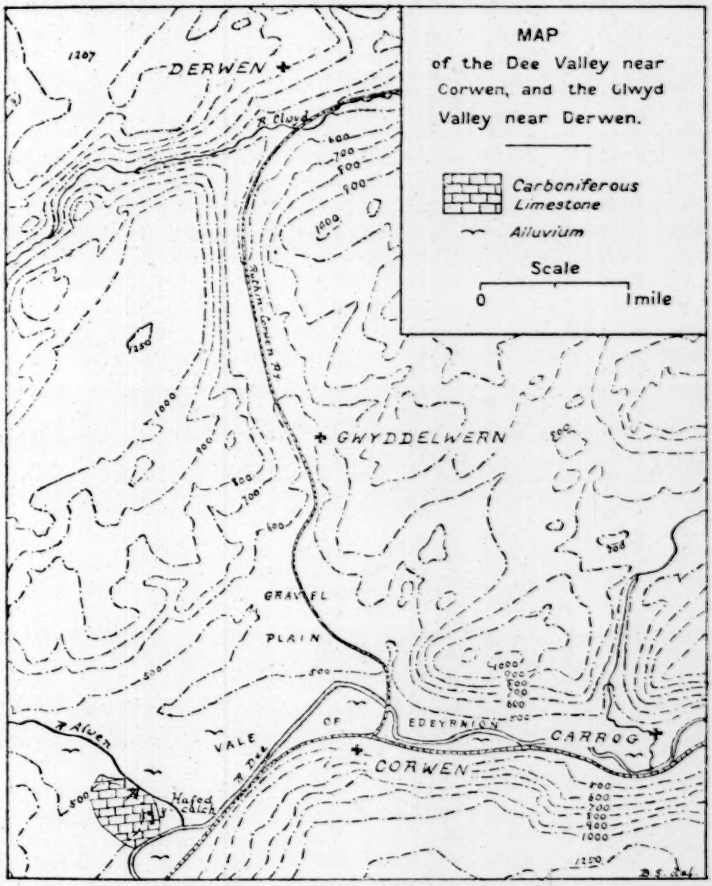
Late-Glacial Gravels.—In many of the valleys of North Wales, such as the Dee, Ceriog, Tanat, Vyrnwy, and Severn, especially in the more mature parts of their courses through the mountains, the recent alluvium is flanked at intervals by terraces of gravel,[3] derived chiefly from the boulder-clay which previously clung to the valley slopes, and still floors the valleys over long stretches. These terraces have usually been regarded as post-glacial, and mapped as ordinary

[1] "Characteristics of British Earthquakes": Geol. Mag., Vol. VII, pp. 410–19, 1910.

[2] Quart. Journ. Geol. Soc., vol. xxxii, pp. 451–3, 1876.

[3] *Summary of Progress* for 1914 (Mem. Geol. Surv.), 1915, p. 17; and for 1915 (Mem. Geol. Surv.), 1916, pp. 11, 12.

alluvium. But just as the highest terraces of the Trent valley between Newark and Nottingham[1] have been shown to be late-Glacial, so also the highest terraces of these mountain valleys are now recognized as having been formed during the retreat of the ice. They are the equivalents of the present day sheets of gravel formed alongside, and at the snouts of, the retreating valley-glaciers of the Yakutat Bay region of Alaska.



Map showing site of Gravel Plain near Corwen.

In broad open valleys, like that of the Trent, the late-glacial terraces are of fairly regular height and level surface; but in mountain valleys, such as those of the Tanat and Vyrnwy, they appear at various heights above the recent alluvium—here 20 feet, there 40 feet—even when the remnants of a dissected terrace are

[1] *Geology of the Country between Newark and Nottingham* (Mem. Geol. Surv.), 1908, pp. 73–6.

fairly close together. At some points, where a valley was winding, narrow and constricted, the escaping glacial waters distributed the débris irregularly, the resulting terrace being of varying height and uneven surface and occasionally pitted with kettle-holes.[1] Where the valleys debouched on the plain, for example where the Vyrnwy leaves the mountains at Llanymynech, the gravel is spread out as a huge apron or fan several miles across,[2] the grade of material becoming finer and finer, and the fan progressively thinner, towards its margins.

Near the mountainous headwaters of the rivers these gravels are usually thin and patchy, and their surfaces are not far above the present alluvial level, whilst the floor (boulder-clay or "solid") upon which they rest is also sometimes above this level. As we follow them down stream towards their lower mountain course the terraces rise higher and higher above the alluvium. Where the rivers debouch on the plain the terraces descend quickly to stream-level. Thus the gradient of the late-glacial streams was flatter than that of the present stream. The gravels themselves also are actually thicker in the middle or lower part of the mountain course than near the headwaters or in the fan. This result was undoubtedly due to the aggrading power of the streams, which were choked with more débris than they could conveniently carry. The dissected terraces that now rise prominently in bold bluffs above the present rivers are not primarily due to any uplift of the land, but to the sinking of the thalwegs of the present streams to a curve consonant with their present volume and rate of flow. During this process the late-glacial gravels have been attacked and redistributed as post-glacial terraces at one or more lower levels.

The gravels are varied in grade and character, in places being fairly clean boulder beds with good-sized erratics, which gradate through finer gravel and silts or clayey gravel into a more clayey deposit that cannot be distinguished easily from the parent boulder-clay. Usually the gravels are roughly stratified, the constituent beds often dipping at steep angles; but in some places they appear to be tossed together in disorder.

The Corwen Gravels (General).—At Corwen there lies an open plain, surrounded by an amphitheatre of mountains, near and north of the confluence of the River Alwen, which flows from west to east, with the River Dee, which flows from south-south-west to east-north-east and then turns due east past Corwen and traverses the famous Vale of Edeyrnion.

The plain is made up of two physiographical units. On the south it consists of the recent flood-plain of the above-mentioned rivers, north of which is a gently undulating plain of gravel extending 1½ miles in the direction of Gwyddelwern and averaging about 550 feet above sea-level, or 100 feet above the alluvial plain of the Dee at Corwen. The two features are separated by a steep bluff.

The gravel plain is about 1½ miles wide near the rivers, but

[1] *Summary of Progress* for 1915 (Mem. Geol. Surv.), 1916, pp. 11, 12.
[2] Op. cit., p. 12.

narrows northward in the direction of Gwyddelwern. It also occurs on both flanks of the flood-plain in the valley east of Corwen. This plain is probably floored by boulder-clay, because its surface is diversified by low patches of undrained marshy ground where the gravels are thin or absent, not through denudation, but apparently because they have never been deposited there. From our own observations this boulder-clay, on the hill-slopes near Corwen and in the Dee valley farther east, comes out from beneath the gravels and river deposits and ascends to higher levels.

Corwen Gravels (*Details*).—We may take it that Mackintosh's description of the succession of the deposits is, as usual, correct. The sands and gravels and the occasional irregular kind of brick-clay over-lie boulder-clay with beds of coarse gravel. The cuttings along the railway north of Corwen, examined by Mackintosh, are now, unfortunately, grassed over to a great extent; but it is still clear that an irregular deposit of layers and lenticles of unevenly-bedded gravels and false-bedded sands and silts on silty loam (? brick-clay) is overlying boulder-clay which appears here and there at about rail level. The beds dip almost due east. A section on the left bank of the Nant Fawr, south of the line, contained masses of gravelly clay, loam, and clayey gravel like boulder-clay with intercalated sands.

About half a mile N.N.E. of Corwen, at the junction of the Carrog road, north of the river, with the by-road to Tan-y-gaer at the east end of the bridge over the railway, 2 feet of soil with boulders rests on 2 feet or more of partly stratified loam with stones, on 3 feet of pebbly gravel. The loam is generally grey or grey-brown, but contained small patches of *brick-red* sand, rusty or yellowish-red sand, and streaks of bluish clay. The stones were partly rounded, partly subangular. Many were of igneous rocks, but none were of types that might have come from the Irish Sea area. There were also occasional cherts and sandstones.

Similar deposits extend as far north as the railway cutting south of Gwyddelwern, where, at about 580 feet O.D., they die out above the boulder-clay.[1]

Turning again to the Dee valley we note that in a pit in the gravel terrace near Groes-faen, about 530 yards west of Carrog Church, the beds were unlike ordinary river gravels. The dip is in all directions, and the deposit is silty, sandy, and gravelly in streaks and patches, often inclined at high angles. Some patches are clayey, others of fine loam with a feel like French Chalk or Fuller's Earth.

The following section was exposed at one point in the south side of the pit:—

		ft.	in.
Coarse gravel and pebbles . . .	about	2	0
Grey silt and sand	,,		6
Pale fine gravel	,,		6
Light-brown finely laminated clay .	,,	1	0

[1] In a north-easterly direction towards Bryn Eglwys the boulder-clay is associated with very little sand or gravel, but makes good drumlin scenery. The exceptions are some morainic sands and gravels in the valley at Bryn Eglwys and near the southward bend of the Afon Morwynion, north of the Carrog Gap.

Amongst the boulders were some of subangular pink crinoidal limestone up to 1 foot in length, fossiliferous rocks from the Bala Beds, subangular cherts, and fragments of local Silurian rocks.

About 300 yards west of Carrog Church there is a large natural hollow or kettle-hole; whilst on the south side of the river, west of Nant Llechlog, the gravels are distinctly moundy and sandy, and possess nothing like the nearly flat surface we should expect if they were normal river deposits. The sand is greyish and the boulders are usually of local rocks, with some of carboniferous limestone, and a few of cherty rock.

Corwen Gravels (*Probable Origin*).—The deposits described above, in their general mode of occurrence, their arrangement and composition, resemble fluvio-glacial accumulations rather than those of an ordinary river. They appear to have been formed during the retreating stages of the Dee valley glacier as marginal and terminal gravels that choked the valley, through which the glacial waters swung from side to side in many interosculating channels.

The general direction of glaciation at the height of the Ice Age, as shown by striæ in the neighbourhood, was from W.S.W. to E.N.E. or S.W. to N.E., with local variations in direction due to the topography of the lower ground. The Corwen amphitheatre, formed by the confluence of the Dee valley with several tributary valleys, was filled at a later stage in the glaciation with a mass of ice from which tongues were thrust out eastwards down the Dee valley, north-eastward up the Morwynion (Bala Fault) valley in the direction of Bryn Eglwys, and northward past Gwyddelwern over a low col into the Clwyd valley near Derwen. A prolonged halt or very slow melting and retreat of the ice in the Corwen amphitheatre favoured the accumulation of a broad outwash fan covering an area of over two square miles, the drainage escaping by the Dee valley.

The Gwyddelwern Valley.—The deep trench-like valley, two miles in length, crossing the watershed between the Dee and the Clwyd north of Gwyddelwern, and now traversed by the Corwen-Ruthin railway, is at first sight suggestive of a gorge cut by overflow waters from a glacial lake impounded in the amphitheatre to the south. However, no water carrying much gravel seems to have entered the Clwyd valley; and since the valley bottom now forms a water-parting covered by boulder-clay, and the western side is a natural escarpment capped by Wenlock Grit, it is more probable that the valley is a natural pre-glacial feature[1] accentuated by the scour of the lower layers of ice moving into the Clwyd valley, and at the time we are considering it was filled by a stagnant melting mass of ice cut off from its base on the south. Had it been used as a channel for overflow water, the boulder-clay at least would have been cleared out and there should have been a steady descent of the floor from Gwyddelwern to the Clwyd valley. The floor, on the contrary, rises north of Gwyddelwern to a mile-long stretch at above 600 feet O.D. before it descends to about 550 feet in the Clwyd valley.

[1] In pre-Glacial days a south-flowing tributary of the Dee must have risen in this valley and have made a near approach to capturing the head-waters of the Clwyd.

Source of Coal in the Gravels.—The occurrence of coal débris in the gravel varying in size from large lumps to fine dust, is a point of great interest. Mackintosh records it (i) in a roadside section immediately east of the Carboniferous Limestone Quarry (Hafod-y-calch) about a mile and a half west of Corwen; (ii) in a railway-cutting some distance east of Corwen and not far from Carrog Station; (iii) north of Corwen, near to where the Ruthin railway crosses the River Dee—this was the principal locality. He was also assured that coal could be found at many other places around Corwen.

After diligent search the author failed to find any coal, probably because of the overgrown state of the cuttings, but residents in the neighbourhood stated that coal had been found in the gravels.

Mackintosh rejected the hypothesis that there might be a concealed outcrop of coal-bearing beds in the neighbourhood, and suggested that the coal was drifted some twenty miles up the winding Dee valley from the neighbourhood of Cefn or Ruabon, during an interglacial submergence. This idea of submergence cannot be maintained.

The coal might have been derived from three possible sources: (1) from the Vale of Clwyd; (2) from the Ruabon district; (3) from a local outcrop.

1. This direction of transport may be dismissed forthwith. South of St. Asaph the movement of ice was from S.W. to N.E., and all waters due to melting ice flowed northward.

2. Any movement of coal from Ruabon must have been against the general direction of glaciation, and must have been caused by ice-bergs or water moving up the Dee valley, and escaping in a south-westerly direction, owing to a huge ice-dam (Irish Sea Ice) across the Dee valley below Llangollen. There is no evidence for this as far as I am aware, nor has it been suggested by my late colleague, Mr. L. J. Wills. The boulders in the Corwen gravels include no rocks from the Irish Sea basin.

3. Thus we are thrown back upon the theory rejected by Mackintosh, namely, that the "very-little-waterworn" fragments of coal could only have come from some now-buried or completely destroyed outcrop in the vicinity.

If we imagine that the Carboniferous Limestone at Hafod-y-calch near Corwen was formerly succeeded by "Millstone Grit" (Cefn-y-fedw Sandstone) and a considerable thickness of normal Coal-measures, it may be difficult to believe that there is a local outlier of the latter that has escaped detection north of the Bala Fault; but when we remember that in the Vale of Clwyd the so-called Millstone Grit is wanting and the Coal-measures are represented by thin purple shales and sandstones[2] with occasional thin coal-seams (one of which had shafts sunk along it) resting upon the highest beds of the Carboniferous Limestone, belief in the occurrence of Coal-measures near Corwen, which is only slightly farther west, is strengthened. In the quarries at Hafod-y-calch

[1] *The Geology of the Neighbourhood of Flint, Mold, and Ruthin* (Mem. Geol. Surv.), 1890, pp. 10–16.

the higher beds of Limestone dip north-eastward at 45° beneath the alluvium of the River Alwen. We may, therefore, be justified in assuming on stratigraphical grounds, and on the evidence of the gravels themselves, that the coal in the latter may have been derived from some portion of an outcrop that was demolished by glacial action. The erosion may have removed the stratum entirely if it were quite a small wedge between the limestone and a branch of the main Bala Fault concealed by the alluvium on the northern side of the outcrop. Our experience shows that such little wedges of rock, clipped in at the junction of important faults like that which traverses the Dee valley from Corwen to Llangollen and the Bala Fault, are the rule rather than the exception.

The shales and sandstones in such an outlier might have yielded some of the material of the finer silts and loams and sandy patches in the late-glacial beds. Whether the sandstones were purple might depend upon whether they were overlain by any Triassic Sand like that which succeeds the purple sandstone in the Vale of Clwyd. No boulders of purple sandstone have been found (it is very friable material), yet the patches of brick-red Triassic-like sand, mentioned above as being found in the drift, are distinctly suggestive.

How far the Trias overspread the Carboniferous rocks in this area is not known, but it is fairly certain on other evidence that the Bala and other large structural faults were in action both before and after the deposition of the Trias.

IV.—Notes on Yunnan Cystidea. III. *Sinocystis* compared with similar Genera.

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B.—Comparison with *Megacystis* (*continued*).

4. *The Thecal Openings.*

b. The Periproct.

In *Megacystis* the periproct—which S. A. Miller always called the mouth—lies between adoral circlets II and III, being bounded by the two posterior facet-bearing plates and the posterior interradial, i.e. 3 of Adorals II, also by 2 or 3 of Adorals III, making 5 or 6 plates in all. The number 5 is the more usual; it occurs in *M. aspera*, *faberi*, *gorbyi*, *indianensis*, *ornatissima*, *ornata*, *parvula*, *parva*, *perlonga*, *plena*, *scitulus*, and *spangleri*, also in British Museum specimens E 7631, —33, —35, —37, —38, ?—39, —40, —42, —44, —45, —74, —76, —77, E 16167, and E 16168 (see our figs. 24, 25, *antea*). The number 6, due to an additional Adoral III, is found in *M. baculus*, *commoda*, *splendens*, and perhaps *gyrinus*, also in E 7630, —34, —36, ?—75, and E 16171 (see our figs. 22, 23, 28, 30, *antea*). This does not seem to be a difference of such constancy as to be relied on for the discrimination of species. It is the sole character distinguishing Miller's *M. commoda* from his *M. gorbyi*, not to mention *M. scitulus* and *M. parva*, which may be younger stages of

the latter species. Similarly such specimens as E 7631, E 7635, E 7638, and E 7644, each with 5 plates, cannot otherwise be distinguished from E 7636 with 6 plates; while E 7630 and E 7634 with 6 plates are otherwise the same as E 7633, E 7640, E 7642, E 7677, and E 16168, each with 5 plates.

There are a few exceptions to the preceding general statements. S. A. Miller (1879) regarded the additional plate in *M. baculus* as an Adoral IV rather than III, but, since his figure lends no particular support to this view, the species has been included in the above list. In *M. gyrinus* (fig. 30) it does seem probable that an Adoral IV enters into the periproctal frame, but it is obscured. In *M. sphæroidalis* (fig 27) there are at least two additional plates in the Ad. III series; indeed the drawing shows three, but the small triangular plate is possibly a corner separated by a crack. Thus the periproct is surrounded by 7 or 8 plates; but this extra number is correlated with the spheroidal shape of the theca rather than with any structural peculiarity in the periproct.

There may also be a reduction in the number of plates. The specimen figured by R. R. Rowley (1903) as "*Holocystites papulosus*?" shows the posterior Adoral II descending on each side of the periproct so as to meet the two Adorals III and to exclude the facetted plates from the periproct, which therefore is surrounded by only three plates. By a similar downgrowth in *M. subovata* the right posterior facetted plate is excluded from the periproctal frame, which here consists of four plates. This is an exaggeration of a tendency which this species shares with *M. ornatissima* (fig. 25) and *M. papulosa*, and which results in an obliquely elliptical periproct with its long axis passing from the left facetted plate to the right of the two Adorals III. In the otherwise similar *M. aspera* this tendency is not manifest, so that the long axis of the periproct is horizontal.

The numerical reduction discussed in the preceding paragraph is due to elimination of a plate or plates from the periproctal frame. Specimen E 7632 presents a reduction to four plates owing to the presence of only one Ad. III in the frame; and this one, being a large plate, may be taken to represent the usual two, whether there has been fusion or no. In other respects this specimen resembles E 7631 and E 7635, and the reduction can only be regarded as a meristic individual variation.

Other exceptions to the general statement are caused by modifications in the posterior interradius of circlet Ad. II. Thus, in E 7639 the left facetted plate is excluded from the periproctal frame by the intercalation of a plate between it and the posterior Ad. II, so that there are 9 Ad. II instead of 8; correlated with this is an extra plate in circlet Ad. I, apparently cut off from the left posterior Ad. I. This intercalation of plates is, oddly enough, not accompanied by an additional Ad. III, so that the number of plates surrounding the periproct is still 5. In E 7675, a somewhat similar intercalation of an Ad. I and an Ad. II only just eliminates the left posterior facetted plate from the periproctal frame, and is accompanied by an additional Ad. III, so that there are 6 plates in the frame

and only just escape being 7; in this specimen, however, the three posterior Ad. III are relatively much narrower than in the more swollen or spheroidal E 7639. In these cases the additional Ad. II seems to be due to nothing more than the development of a suture separating the prolongation of the left posterior facetted plate from the body of the plate, for the sake of greater flexibility; in harmony with this the adjacent Ad. I also becomes longitudinally divided, but its suture in both specimens is a very close one and not easy to see.

In no specimen of *Megacystis* recorded or known to me are the anal valves (or periproctals) preserved. The usually rectilinear outline of the opening, with its slightly rebated sides, denotes that the periproctals were, as in *Sinocystis*, triangular plates. Their number may be inferred from the number of sides possessed by the periproct. This is not necessarily or invariably the same as the number of bounding plates. Occasionally the sides of the periproct, and consequently the periproctals, do approximately correspond with the margins of the bounding plates in both position and number, e.g. E 7634, and Miller's figures of *M. parva* and *M. scitulus*, his fig. 6 of *M. commoda* (*not* the figure copied *antea* fig. 23), and less closely his figure of *M. gorbyi*. Frequently the sides correspond with the plates in number but not in position, and in this case the angle at which two sides meet lies not at the suture between two bounding plates but at some distance from it, so that the free margin of the plate is notched. This notching may affect one or more or even all plates; thus E 7640 and E 16168 have each 5 sides and 5 bounding plates, and all the latter are notched. Usually, however, the correspondence is fairly exact with Adorals II; it is the Adorals III that tend to be notched. When the numbers correspond the notching may be confined to the left-hand Ad. III (e.g. E 7642, E 7645, E 7677); when there are 6 sides and 5 plates, the notching extends usually to the right-hand Ad. III (e.g. E 7638, E 16167) or it may instead affect the left Ad. II (as in E 7637). In the cases (probably rare) when 6 plates surround a 5-sided opening, the median Ad. III has a conspicuous median notch (e.g. E 7636). Sometimes it is impossible to identify any precise number of sides, since all angles seem rounded off so as to produce a circular or elliptical opening. This is particularly noticeable in the *M. ornatissima* series (see p. 257) and in *M. sphæroidalis*. Possibly in such forms the triangular periproctals were separated from the periproct margin by a flexible finely-plated membrane. In *M. aspera* and in the specimen described by Rowley as "*Holocystites papulosus*?" (see p. 257) the periproct has a quadrangular outline and may have been closed by four valves.

The preceding facts show that, though there were certain tendencies in the several groups of species, still there was no fixity. Neither the number of the periproctals nor that of the sides of the periproct can be regarded as a specific character. Possibly the sides of the periproct may originally have corresponded with the margins of the bounding plates, and this correspondence is usually retained in the adoral half of the periproct; but the variability in the third adoral circlet may have conflicted with the persistent conditions in the

second circlet, and so induced shiftings or numerical changes in the opening between them. In *Sinocystis* the number of the periproctals was more fixed, being six in *S. loczyi* and *S. yunnanensis*, five in *S. mansuyi* (*antea*, 1918, p. 511). A rough correspondence with the bounding plates is shown in Reed's pl. i, fig. 3, but the available evidence is not enough to warrant any general statement. The greater irregularity and variability of the thecal plates in *Sinocystis*, as well as the absence of any connexion between the periproct and the relatively fixed Adorals II, suggest that the constitution of the theca had here little influence on the periproctals. The preservation of the periproctals in the fossils of *Sinocystis* indicates that they were more solid, or more firmly united to the frame than in *Megacystis*. Therefore, in *Sinocystis* the number of the periproctals dominates the bounding plates, whereas in *Megacystis* it is more affected by them. To some extent the periproctals and the bounding plates form two systems, each subject to its own hereditary and environmental influences, and therefore liable to be brought into conflict.

c. The Hydropore and Gonopore.

When the various openings in *Megacystis* were discussed by P. H. Carpenter in 1891 (J. Linn. Soc., Zool., xxiv, pp. 48–50), on the basis of Miller's figures, he recognized all four openings in *M. commoda*, though in general he regarded the openings as confined to peristome, periproct, and "nephridial opening" [=hydropore], and in some cases (e.g. *M. elegans*) to the two former alone. His view was that the periproct served as an osculum, embracing the gonopore as a rule and in some cases the hydropore as well.

Jaekel (1899) did not specifically mention or figure the hydropore and gonopore in his *Trematocystis*, but, since he regarded the presence of both those openings as characteristic of the Aristocystidæ, he must at any rate have assumed their presence in *Trematocystis*.

Miller's figures and descriptions are rather insecure evidence, and there are reasons for believing that the opening observed in a number of species cited by Carpenter, and regarded by him as "excretory" or "nephridial" and "equivalent to the fourth opening of *Aristocystis* and *Glyptosphæra*", i.e. what we now take as the hydropore, is really the gonopore, and that the hydropore, though present, was not observed. The reasons for this belief are first a morphological argument, secondly comparison with other genera, thirdly actual observation of the British Museum material.

The morphological argument depends on a structural feature to which attention has not, it seems, previously been directed. This is the tendency in so many of these primitive echinoderms for the hydropore to be a slit crossing the suture between two plates. So it is in *Edrioaster* (Bather, Studies in Edrioasteroidea, Geol. Mag. 1914, p. 168, pl. xi, fig. 2), *Aristocystis* (Barrande, 1887, Syst. Silur., vol. vii, pl. ix, figs. 2, 3, 6, 13; Bather, 1906, Palæont. Indica, II, 3, p. 9.), *Sinocystis* (*antea*, 1918, p. 535), *Pleurocystis* (Jaekel, 1899, Stammesges. d. Pelmatozoen, pp. 101, 138), *Schizocystis*

(Bather, 1900, Treatise, p. 61, fig. xxv), *Cryptocrinus* (*op. cit.*, p. 70, fig. xxvii, 2, after Jaekel), and other genera.

The gonopore, on the other hand, is a simple hole, as often as not through the middle of a plate. It further differs from the hydropore in being frequently (perhaps normally) closed by valves, and these, as in the case of the periproct, give it a rectilinear—often pentagonal—outline. It is so small itself, and its valves are so minute, that the structure often cannot be made out, even if the pore itself be not obscured by the processes of petrifaction.

It seems probable that both hydropore and gonopore originally emerged between thecal plates, and that they were subsequently surrounded by the plate-stereom in the same way as the podia of echinoids have become surrounded by the ambulacral plates between which they originally passed. The gonopore of the Cystidea, being the outlet of a single gland, has remained a simple pore and has been wholly occluded by a single plate. It is not so easy to see why the hydropore should affect two plates. The curious bilateral folding of the stone-canal in Asteroidea and the alleged occasional paired hydropore of the embryo might suggest that here was a relic of the bilaterally symmetrical Dipleurula. On the other hand, the obliquity of the hydropore-passage in *Edrioaster* and elsewhere shows how two plates may be involved without any suggestion of duplicity. The essential difference between hydropore and gonopore seems to be the conversion of the former into a filter through the formation of numerous minute pores connected by a ciliated channel on the exterior. This channel extended from the original opening in both directions. For the present this must be taken as a fact, but we have still to explain the direction followed and its frequent regular curvature. In later forms these primitive features were obscured by the excessive folding that produced the characteristic madreporite.

If the preceding statements be accepted, we are provided with a touchstone enabling us in most cases to decide which of two visible openings is the hydropore, which the gonopore, or, in the case of only one visible opening, to say which of the two it is. For example, in *Cheirocrinus constrictus* Bather (1913, Trans. R. Soc. Edin., XLIX, ii, p. 445, fig. 51), the "extended pore" that crosses "the curved suture" is probably the hydropore, and the "poriferous elevation at the other end of the plate" is probably the gonopore; the converse interpretation was tentatively suggested in the memoir. In the "Treatise on Zoology" some openings are perhaps lettered wrongly: in *Echinosphaera*, p. 53, fig. xiv, and *Sphaeronis*, p. 72, fig. xxxviii, the tri-valved opening marked M, and in *Protocrinus*, p. 75, fig. xlv, 1, the pore through the plate marked M, should all be the gonopore. The test will be applied to *Megacystis* later.

In comparing *Megacystis* with other genera, Carpenter went on the belief that there was no hydropore or gonopore at all in *Agelacrinus*, the Caryocrinidae, and *Malocystis*, and no separate gonopore in seven other genera that he mentions. Therefore he was ready to admit similar conditions in *Megacystis*. Since then we have learned that there is a hydropore in the Edrioasteroidea (S. R.

Williams has just claimed to have detected it in *Agelacrinus* itself), the Caryocrinidae, and *Malocystis*; also that there is a gonopore, probably or certainly with a hydropore also, in *Caryocystis*, *Cryptocrinus*, *Cheirocrinus*, *Orocystis*, *Sphaeronis*, and *Sphaerocystis* (here Schuchert, 1904, calls it the hydropore, although he acknowledges another opening as "madreporite"). In a word, it is no longer safe to ascribe the apparent absence of these openings from any cystid to anything but our ignorance and the extreme difficulty of dispelling it. Thus the argument from other genera, so far from supporting the views of Carpenter, points to the presence of both gonopore and hydropore in all species of *Megacystis*.

Lastly we come to the evidence of the British Museum specimens. These, even when they are closely similar in all other respects, do, it is true, present some interesting variations in the shape and distribution of these openings, but both openings can nearly always be detected.

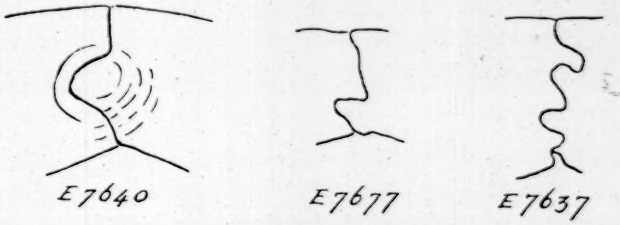

FIG. 31.—Hydropore-sutures in *Megacystis*.
These all occur in specimens of *M. gorbyi* character, and show the replacement of the hydropore-slit by a sinuous suture between the posterior Adorals I. × 10 diam.

The Hydropore is plainly seen in ten specimens, and faintly suggested in about six more. In the remainder it has been obscured by crushing or by encrusting organisms, or the plates are absent. Normally it appears as a narrow groove or a dark line, indicating a slit, crossing the suture beween the two posterior Adorals I at right angles, just outside the peristome rim. In E 16168, identified as *H. scitulus* by S. A. Miller, the length of the slit is 1·2 mm., and this seems to be above the average. In E 7638 the slit seems to be continued on the right into a sinuous suture, which reaches the right posterior facetted plate and so bisects the right posterior Ad I. Sometimes the slit is on an eminence, as in E 7633, ? E 7635, E 7642. All these specimens are, like *M. scitulus*, of *M. gorbyi* character. In E 7673, a strongly pustulate form, the position of the hydropore seems indicated by a rather irregular rim (*antea*, fig. 29).

In a few of the specimens where the hydropore is less plain, the existence of some such structure is suggested by a remarkable sinuosity of the suture (fig. 31). In E 7636, a dark spot indicates the actual pore, and the suture just here makes a slight bend. In E 7644 the suture is sharply bent where it crosses the hydropore-slit. In E 7640 no opening can be detected, but in the middle of its course the suture takes a sharp semicircular curve to the left, and

all this tract forms a gentle eminence. In E 7677, there is a similar sharp, but less regular, curve to the left at the aboral end of the suture, and the rest of the suture is waved; there is no obvious eminence. In E 7637 there are three sharp curves to the left and three to the right, beginning with a small one at the aboral end on the left and increasing in swing towards the oral end; although there is no trace of a pore or of an eminence, it cannot be doubted that this exaggerated sinuosity does in some way represent the foldings of the hydropore.

The variations here described bear little or no relation to differences that might be taken as specific. They show how easily one may overlook the indication of a hydropore, especially when it is merely a passage between two plates; and they warrant the conclusion that a hydropore is present in all species of *Megacystis*, though previously recorded only in *M. commoda*, *M. gyrinus*, and *M. hammelli*.

The Gonopore appears in one of two distinct places. In eleven specimens out of the eighteen in which it is visible it pierces the posterior Ad. II (*antea*, figs. 24, 26). It may be near the centre or in either the adoral or aboral half of the plate, but always lies to the left of the median line (E 7631,—32,—35,—36,—38,—41, —44,—73,—74,—75). In E 7639, where there are abnormally two posterior Ad. II, the gonopore is on the left-hand one. In the remaining seven specimens the gonopore is on the right slope of the left posterior facet-boss, sometimes very close to the brachial facet itself, e.g. ·7 mm. distant in E 7634, E 7640, ·6 mm. in E 16168, ·5 mm. in E 7630, ·4 mm. in E 7677, and ·3 mm. in E 7633 (*antea*, fig. 22). This position is more than a mere crossing over the suture between the facet-bearing plate and the interradial. Only in E 7642 is the opening as near to that suture as it is to the facet, the respective distances being each 1·3 mm.; in this particular case the left posterior facet is curiously widened in the direction of the gonopore, as though stretching out to meet it. Remembering that in the Crinoidea the genital strand passes into the arms, some may see here the beginning of a similar relation. The brachia of a crinoid, however, are outgrowths of the theca and contain extensions of the body-cavity; in this they differ fundamentally from the brachioles of a cystid, which are purely epithecal structures, and contain, so far as one can see, no such extensions. Carpenter (1891, p. 49) drew attention to a somewhat similar variation in two of Barrande's examples of *Aristocystis bohemica*: "In one of them the distal opening, which I regard as genital, is on the very edge of the anal aperture, while in the other it is nearly halfway up towards the peristome"; it remains, however, on a plate distinct from that connected with the brachiole.

From Miller's descriptions or figures it is inferred that the gonopore is on the posterior Adoral II in nine species, viz., *M. baculus*, *commoda*, *faberi*, *hammelli*, *ornata*, *parvula*, *rotunda*, *scitulus*, and *splendens* (*antea*, figs. 23, 28); near the left posterior facet in four species, viz., *M. gyrinus* (fig. 30), *plena*, *pustulosa*, and *subglobosa*. It has not been recognized in any other of the described

species. These numbers, as well as those drawn from the British Museum specimens, suggest that the position on post. Ad. II was the more usual. Since either position is found in specimens otherwise identical, the character cannot well be taken as diagnostic of species. Neither does there seem any convincing reason for regarding it as a secondary sexual character.

When clearly seen, the gonopore has a pentagonal outline, indicating that it was closed by five valves. In E 7632 it has a slightly raised rim which appears toothed, perhaps owing to the preservation of portions of the valves. In E 7636, the opening is hexagonal. When the pore pierces post. Ad. II, it is generally flush or on a very slight eminence; the latter feature is seen in E 7631 (*antea*, fig. 24). When the pore is near the facet, it is always on a rounded eminence, which in E 7630 and E 7634 is so pronounced as to simulate the root of a young pelmatozoön.

In two of the specimens the gonopore seems to be double. In E 7630 (fig. 22), where it is on an eminence near the facet, there is close beside it another smaller eminence with a pore. In E 7635, where it is on the left side of post. Ad. II, the appearance is rather obscure, but there certainly seems to be a smaller opening to the right of the main pore, and barely separated from it.

As compared with *Sinocystis*, the position of the gonopore is here slightly more definite, and in all cases is well above the periproct (not on a level with it) and nearer to the subvective system.

(*To be continued.*)

REVIEWS.

I.—Military Geology and Topography. Prepared and issued under the auspices of the National Research Council, Division of Geology and Geography. Edited by Herbert E. Gregory, Ph.D. pp. xv + 280. New York: Yale University Press. London: Oxford University Press. Price 5*s.* 6*d.* net.

THIS book was specially prepared in response to many requests for guidance in the presentation of courses, required by the Committee on Education and Special Training of the War Department, for the training of officers for the new American Army.

The list of collaborators in its preparation is a long and distinguished one, including thirteen University professors and lecturers and several well-known officers of the Geological Survey of the United States.

A modest statement appears in the preface: "The book is the result of a preliminary effort, and its authors hope that it will be a nucleus about which will gather material for a more complete volume."

The fact that the American War Department recommended that officers should be taught geology and geography is worthy of attention. When the entry of America into the War was decided upon, American officers visited the Western Front to study conditions and methods in order to profit by the knowledge gained for the

training of their new Army. They were at once struck by the great increase, as compared with former wars, in the numbers and varieties of maps and also by the far greater employment of mining. At one period the Western Front was to all intents and purposes in the hands of the mining engineers of both sides, mine and countermine determining the success of costly local operations. It was therefore natural to assume that the study of mining would form a greater part of the education of the military engineer of the future than it had done in the past. The study of mining is closely linked with that of geology. Again, it was found that geological experts were attached to the headquarters of the Armies, the most highly organized branch being found in the German Army. There were also special branches of the engineering staff dealing exclusively with water supply. The authors had, therefore, a wide field to cover, and by the nature of the case were compelled to be very concise. They have acquitted themselves very well, for the book contains just as much geology and topography as the military engineer—that jack of all trades—need know, clearly and attractively presented.

The subject first studied is that of rocks and other earth materials. The scheme adopted is to describe the rock and give an account of its occurrence, then to note its practical utility, as for example in the preparation of concrete. Rock weathering is then shortly described as its direct bearing on military work is only slight. Next streams, lakes, and swamps are considered, and examples, from the War and history, of their influence on military campaigns are frequently inserted.

The study of water supply is gone into pretty thoroughly, occupying fifty-two pages. This attention is indeed merited, good and plentiful water being most important to the health and comfort of troops in any campaign. Theory and practice are skilfully intermingled.

The chapter on land forms, in which field of study American geologists lead the way, enables the reader to appreciate the forms characteristic of the different kinds of rocks.

The portion of the book devoted to map-reading and interpretation is not quite so good as our own Army handbook on the subject, except that the interpretation is treated from the geological point of view. It is also interesting to note that the authors make no attempt to explain geological map-reading; probably they consider this should be left to the expert.

The last chapter deals with the economic relations and military uses of minerals.

Throughout the text numerous references to more advanced works by American authors are given. The book is clearly printed, profusely illustrated with excellent photographs and diagrams, and is reasonable in price.

In spite of the fact that the book was written for the special purpose of training officers for the War just concluded it would be of great value to officers, particularly to those of the Royal Engineers, as the essentials of their requirements of geology and topography are collected together under one cover. B. Lightfoot.

II.—The Origin of Serpentine: a Historical and Comparative Study. By W. N. Benson. Amer. Journ. Sci., vol. xlvi, pp. 693–731, 1918.

FOR some years past Professor Benson has made a comprehensive study of serpentine rocks, arising from his work on the Great Serpentine Belt of New South Wales. He has had the advantage of working at Cambridge, with the advice and assistance of Professor Bonney, and has also visited many European localities and consulted some of the leading Continental authorities and examined their material. The results of his investigations are brought together in this valuable paper, which begins with a short but clear account of the historical development of the views of the leading petrologists on the genesis of serpentine. Starting from the now universally accepted view that serpentine rocks are altered deep-seated peridotites, consisting mainly of olivine and pyroxene, the author shows that in many cases, at any rate, the process of serpentinization is essentially of a pneumatolytic nature, analogous to a certain extent to the formation of greisen, water and carbon dioxide being the chief agents concerned; coarse-textured veins of serpentine and olivine occasionally found in such rocks show some resemblance to granitic pegmatites. Serpentine with mesh-structure (chrysotile) is usually found in undisturbed regions, while antigorite is specially characteristic of high pressure; the latter is sometimes formed by dynamic metamorphism of the former. It appears that although serpentinization is usually due to the pneumatolytic action of the residues of the same magma that gave rise to the original peridotite intrusion, nevertheless there have often been several intervening intrusions of differentiates from this magma, ranging even to acidic composition, hence the process of serpentinization may appear to be due to a granitic intrusion; however, geologically speaking, the interval is short and the alteration is completed before the end of the same orogenic and eruptive phase. It is also considered possible that in certain cases a peridotite which has escaped hydration by its own magmatic waters may subsequently be changed to serpentine by the action of deeply circulating epigene waters. At any rate, it is clear from the facts stated by Professor Benson that it is no longer permissible, as has been done by many writers, including the present reviewer, to consider serpentinization as an effect of weathering now in general operation near the earth's surface; it must for the future be relegated to the category of deep-seated late-magmatic phenomena, which for want of a better name are generally classified under that blessed word "pneumatolytic".

R. H. R.

III.—Bidrag til Finmarkens Geologi. By O. Holtedahl. Norges Geol. Undersök, No. 84, with English Summary. pp. 314, with 21 plates and 2 coloured maps. Kristiania, 1918.

AS the result of careful field-work extending over nearly six months in the years 1914–17, the author shows that Dahll's classification of the rock-systems of the extreme north of Norway

cannot be maintained; his Gaisa system in particular includes a large number of rocks of different ages.

The oldest rocks in the south of the district are of pre-Cambrian age, comprising hornblende schists, quartzites, and crystalline magnesian limestones; towards the west, in Jori, is a region of less advanced metamorphism with slates, dolomites, and volcanic rocks resembling those of the Kiruna district in Sweden, while east of the River Tana the country is mainly composed of gneisses and granites; both of these types are probably younger than the schists of the south.

The oldest Palæozoic zone in Finmarken resting on a peneplain of erosion is a shale with *Platysolenites antiquissimus*, a fossil found in many places in the Lower Cambrian of Scandinavia and the Baltic region; this is supposed to be part of a Cystidean. This zone is clearly a continuation of the *Hyolithus* zones of Sweden and Norway. Above this comes the very thick Porsanger Sandstone with shales and dolomite, the latter enclosing laminated structures called by the author stromatolites and referred by him to chemical precipitation possibly brought about by algæ. These structures and the silicified layers in the dolomite strongly recall the characters of the Durness Limestone, and the series is assigned to an Ozarkian-Canadian age. Unconformably above the Porsanger Sandstone comes a younger series with conglomerates and tillites, formerly included in the Gaisa Series; the tillites of the Varanger Fjord were well described by Sir A. Strahan in the Quarterly Journal for 1897. The author concludes on what appears to be good evidence that these deposits are of Ordovician or possibly Silurian age.

All these rocks are again overlain in the Alten division of the district by the mylonitic rocks of the Caledonian thrust zone. It was formerly believed that these overthrust rocks were of pre-Cambrian age, but there is no evidence to support this view, and it is concluded that they are simply highly metamorphosed representatives of the unaltered Palæozoic rocks below the thrust. The resemblance to the general succession as seen in the North-West Highlands is obvious, and this memoir is of great interest on account of its bearing on the problems of British stratigraphy.

IV.—Falklandia. By J. M. Clarke. Proc. National Academy of Science of U.S.A., vol. v, No. iv, pp. 102–3, April, 1919.

IN the valuable monograph published in 1913 by the Geological Survey of Brazil (Fosseis Devonianos do Paraná), Dr. J. M. Clarke included a discussion on the palæogeography of the austral lands in Devonian times. He pointed out that the extent of the Southern Devonian shore faunas indicated the union of Gondwana-land and Antarctis during Devonian times. The Devonian of these latitudes is a unit both in life and sedimentation. In the present short paper Dr. Clarke proposes the name "Falklandia" for the "continental land which, during the Devonian period in the occidental parts of the Southern Hemisphere, preceded Gondwana-land and Antarctis". It is considered that other names, such as Frech's "South Atlantic Island", which have been suggested for the Pre-Gondwana austral lands, have been founded on insufficient evidence.

V.—The Tin Field of North Dundas (Tasmania). By H. Conder. Geol. Surv. Bull. No. 26. 96 pp. and 4 maps. Hobart, 1918.

THIS area consists of a region of slates, sandstones, grits, and conglomerates, with volcanic tuffs, their early Palæozoic age being proved by the discovery of some badly preserved graptolites. The mineralization appears to be due to the intrusion of a granite magma of Devonian age, which gave rise first to porphyroids, then to the main acid mass with a basic marginal facies: certain masses of diabase may be of much later date. The metalliferous deposits belong to several different types, as follows: quartz-tourmaline lodes, quartz lodes, pyritic and pyrrhotitic lodes, and dolomitic lodes, with other less well-defined types. The chief minerals are ores of tin, lead, zinc, and silver, together with pyrite and pyrrhotite.

VI.—Fossil Cockroaches.

AMONG Mr. Bolton's energetic efforts to seek out all the Carboniferous Cockroaches, we note the Manchester Museum publication, No. 80, describes those specimens obtained by Mark Stirrup from Charles Brongniart. These came from Commentry and are now in the Manchester Museum. Among them is a fine dragon-fly, *Megagnatha odonatiformis*. To these forms have lately been added a series from the Pennsylvanian of the United States, described and figured by Cockerell in the Proc. U.S. Nat. Mus., liv, 1918. Eight in number, they comprise two new genera, *Cobaloblatta* and *Ptilomylacris*.

VII. — Annual Report of the Director of the Geophysical Laboratory, Washington, for the year 1918.

THE publication under review is the last of a series of Annual Reports which we owe to Arthur L. Day as Director of the Geophysical Laboratory of the Carnegie Institution. It must be a source of great gratification to Day to realize the high position which the Geophysical Laboratory has won for itself in scientific regard in the course of a comparatively few years.

The present Annual Report leaves untold the story of the year's progress achieved in the laboratory, for nothing but war work has been attempted. It gives, however, a most valuable résumé of papers written by members of the staff and published in various American scientific journals. These papers, it is explained, are for the most part records of researches in progress at the time of the entry of the United States into the War.

The summary thus afforded exactly meets the requirements of geologists the world over. It is an easy matter to turn from it to the journal containing the particular paper to which more detailed reference seems desirable. It is to be hoped on this account that the Annual Reports have a wide circulation.

Thirty-three papers in all are considered. Several are concerned with laboratory technique. A few, again, relate to matters of predominantly physical or chemical interest, as, for instance, the Planck radiation law, the place of manganese in the Periodic Table judged

by the colour of its chemical compounds and the high-temperature specific heats of platinum, silica, and the alkali felspars.

Three papers deal with glass. One of them, by N. L. Bowen, is entitled "The significance of Glass-making to the Petrologist". The summary given is as follows:—

> Contrary to certain claims that have been made, glass-making processes offer no support to the belief in liquid immiscibility among silicates, nor to the belief in a significant density stratification in a mass wholly liquid. They do, however, suggest the importance of gravity acting on a mass partly solid and partly liquid, and emphasize two stages: (1) that at which there is much liquid and little solid, and (2) that at which there is little liquid and much solid. In magmas these two stages are probably those during which the most significant results in the way of differentiation are accomplished.

Bowen's paper is a valuable contribution to a difficult subject. Field experience, especially in Mull, has led the present reviewer to favour the opinion that gabbro and granophyre are sometimes immiscible for a short range of temperature before crystallization sets in in earnest. Evidence pointing in this direction is often wanting even in the field, and under certain experimental conditions it might well be absent, owing, for instance, to such complications as metastable miscibility.

Various other papers treat the side of petrological inquiry that receives its inspiration from the writings of Willard Gibbs. Thus, G. A. Rankin and H. E. Merwin illustrate the temperature-concentration relations of the various crystalline phases in equilibrium with liquid in the ternary system $MgO - Al_2O_3 - SiO_2$. Arising from this we find a reinvestigation of the melting points and stability relations of cristobalite and tridymite, carried out by John B. Ferguson and H. E. Merwin. Cristobalite is confirmed in its claim to be the high-temperature form of silica.

Ferguson also gives an account of the equilibrium relations of the volcanic gases CO_2, CO, SO_2, and S_2.

Henry S. Washington has quite a number of papers to his credit. Three refer to Italy, and include a consideration of the leucitic lavas as a potential source of potash. Of his other works may be mentioned a compilation and discussion of chemical analyses of igneous rocks, 1884 to 1913, and a new edition of his *Manual of the Chemical Analysis of Rocks*. He also gives an account of a method of calculating from chemical analyses of clays the mineral composition "generally quartz, felspar, and kaolin". No novel principle is involved, but the procedure is recommended as "of great simplicity and accuracy".

E. B. Bailey.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

May 21, 1919.—Mr. G. W. Lamplugh, F.R.S., President, in the Chair.

The following communications were read:—

1. "The Silurian Rocks of May Hill." By Charles Irving Gardiner, M.A., F.G.S. With an appendix by Frederick Richard Cowper Reed, Sc.D., F.G.S.

The district of May Hill comprises a small area of ashy grits, which Dr. Callaway in 1900 considered to be of Pre-Cambrian age. The evidence now available does not seem to warrant any definite opinion as regards the age of these beds. Llandovery sandstones are extensively developed, and are of Upper Llandovery age. They consist of a lower division of coarse sandstones and conglomerates, and an upper one of fine sandstones. No beds of Tarannon age occur.

The Woolhope Limestone is never thick, and fossils in it are very few. The Wenlock Shales and Limestone show a normal development. The latter is very fossiliferous, and shows coral-masses in the position of growth.

The Ludlow Beds are, in the main, of a brown sandy nature. No Aymestry Limestone is present, and the Ludlow Beds cannot be separated into an upper and a lower division. A bone-bed is seen at the top of the Ludlow Beds by the side of the road near Blaisdon. This was described by H. E. Strickland in 1863, who saw it in the railway-cutting close by.

Downton Sandstone occurs in the north of the district, where it is about 300 feet thick; but it is only some 11 feet thick near Blaisdon on the south. It is conformably overlain by Old Red Sandstone.

The Silurian rocks are arranged in an anticline in the part of the district where May Hill is, but elsewhere show no such arrangement. On the north they are much broken by faults. Near Flaxley, in the extreme south, rocks from the Wenlock Shale to the Old Red Sandstone inclusive are overfolded.

Dr. F. R. C. Reed describes a new species of *Lichas* from the Wenlock Limestone and a new variety of *Calymene papillata*.

2. "The Petrography of the Millstone Grit Series of Yorkshire." By Albert Gilligan, D.Sc., B.Sc., F.G.S.

Since the pioneer work of Sorby on this subject, published in 1859, the clastic deposits of the Carboniferous System have been unaccountably neglected by petrologists. The author has followed the usual methods of investigation, and has collected a large number of pebbles and specimens from widely separated areas which have been examined microscopically. Numerous separations of the heavy minerals have also been made from all types of rock, varying from coarse conglomerates to shales, which occur in the series.

Quartz-pebbles are dominant, and vary much, both in size and in colour. The largest are found in the coarse-grained beds at the bottom and top of the series. They often show double-sphenoid forms suggestive of derivation from mechanically deformed rocks, which inference is shown to be correct by the undulose extinction, the crenulate and mylonized structure seen when sections of them are examined in polarized light.

Blue and opalescent quartz is very common, containing inclusions often of indeterminable character arranged in streams or rows: others contain liquid with movable bubbles, while needles and hair-like inclusions are also usually present. The quartz of the

finer material is similar in character, and the inclusions in the grains suggest that it has been originally derived for the greater part from such rocks as gneisses and schists.

Felspar pebbles are abundant in all the coarse beds. They are dominantly microcline or microcline-microperthite, and when broken are found to be perfectly fresh, the lustre of the cleavage-faces being most remarkable. Blebs of quartz are frequently present in these felspars. In many of the rock-sections, grains of microcline and oligoclase, quite fresh and unaltered, are common. Fragments showing the intergrowth of blue or opalescent quartz and microcline are fairly abundant.

Chert pebbles are plentiful in the coarse beds at the base of the series; they are also sporadically distributed throughout the upper beds, and in some of these oolitic structure has been observed. One pebble of silicified oolite shows a microscopic structure strongly resembling a structure found in the Torridon Sandstone. A few fragments containing microscopic organisms have also been obtained.

Mica is not plentiful in the coarser beds, but increases in amount with decrease in grade of the material.

From the Middle Grits of Airedale a remarkable assemblage of pebbles has been obtained, including the following types: gneisses, granites, schists, quartz- and felspar-porphyries, quartzites, grits, sandstones, and mudstones. One of these pebbles has been recognized as the black schist associated with the Blair Athol-a-Nain Limestone of Scotland. Another pebble is doubtfully referred to the rhomb-porphyry of the Christiania region.

The results of the investigations into the heavy mineral contents may be summarized as follows, dividing for this purpose the Millstone Grit Series into three more or less well-defined groups:—

(*a*) Lower Division—Base of the Ingleborough Grit to the base of the Leathley Sandstone.
(*b*) Middle Division—Leathley Sandstone to the base of the Flags below the Rough Rock.
(*c*) Upper Division—Flags and Rough Rock.

The minerals are in decreasing order of relative abundance:—

(*a*) Coarse beds contain garnet, ilmenite and leucoxene, zircon, tourmaline, rutile, monazite and magnetite.
Fine beds contain zircon, rutile, garnet, and tourmaline.
(*b*) Coarse beds contain zircon, rutile, garnet, tourmaline, ilmenite and leucoxene, magnetite and monazite.
Fine beds contain zircon, rutile, tourmaline, and garnet. Some of the separations from the shales of Otley Chevin were almost entirely zircons, only a few grains of other minerals being present.
(*c*) Coarse beds contain garnet, ilmenite and leucoxene, zircon, rutile, tourmaline, monazite and magnetite.
The Flags at the base of the Rough Rock contain zircon, rutile, garnets, and tourmaline.

The monazite has been determined by spectroscopical and chemical tests.

In view of the similar work which is being done among the younger sedimentary rocks, it is important to record that, although the author has not yet discovered staurolite in the Millstone Grit, he has found it to be common in some of the sandstones near the

top of the Coal-measures in Yorkshire, namely, Ackworth Rock, Pontefract Rock, and the Red Rock of Rotherham, and also in basement Permian at Conisborough.

In Yorkshire alone, to which area for the greater part the researches have been limited, the Millstone Grit forms the surface of 840 square miles; while, if that which lies beneath the newer rocks and that represented by outliers on the Pennine Fells were taken into account, it must have extended over at least 2,000 square miles. If 1,000 feet be taken as its average thickness, the Yorkshire Millstone Grit would represent a volume of 400 cubic miles, the equivalent of a range of mountains 800 miles long, 1 mile high, and 1 mile wide at the base.

The beds attenuate southwards, and the only possible conclusion from their stratigraphy, reached by Sorby, and later confirmed by Edward Hull and A. H. Green, is that the material was derived from a northern source. The evidence which the author has obtained corroborates this view.

The ancient land-mass of the Midlands must be excluded as a possible source for more than a small fraction of the material, both on account of the inadequacy of the area and on account of its lithological constitution.

The Lake District was probably submerged in Viséan times, and for that reason could not have supplied material to the Millstone Grit. Further, the abundance of monazite in these beds and its absence from the granites of the Lake District, as shown by R. H. Rastall and W. H. Wilcockson, definitely exclude that area. Southern Scotland may have contributed to the homotaxial deposits farther north than Yorkshire, but inadequacy of area is again pointed out.

Thus, by elimination of other areas for one reason or another, the author shows that the most probable source of the material lay still farther north in a land-mass of continental extent, of which Scandinavia and the North of Scotland represent the remaining fragments. In these areas alone can the mineralogical demands of the Millstone Grit be satisfied, and the author institutes a comparison between the Torridon Sandstone and the Millstone Grit, which shows that their similarity of constitution is altogether too great to be merely fortuitous. He infers that, despite their disparity in age, they had a common source in that northern continent.

That continent had probably been base-levelled in pre-Millstone Grit times, and the advent of this period was brought about by renewed uplift rejuvenating the rivers, which removed the old rotted soil-mantle and exposed fresh unleached rock. The extension of the land-mass across the North Atlantic would produce a monsoon type of climate, and the rock-débris broken up under semi-arid conditions, as seems clear from the extreme freshness of the felspars in the grits, would be swept along rapidly by floods to the deltas of the large rivers.

The author concludes by postulating one such large trunk river flowing southwards from the northern continent, and receiving

tributaries from what are now Northern Scotland and Scandinavia, debouching somewhere off the north-east coast of England, the deltaic material of which (now consolidated) forms the Millstone Grit.

II.—Geologists' Association.

June 6, 1919.—Mr. J. F. N. Green, B.A., F.G.S., President, in the Chair.

The following paper was read: "Old Age and Extinction in Fossils." By W. D. Lang, Sc.D., F.G.S.

I. A Biological view-point.

The phenomena of old age and extinction must affect our general biological views; and these, in turn, are reflected in our attitude towards these phenomena. Vitalistic (or automatic) and mechanistic (or environmental) views are contrasted, and emphasis laid on the former. An organism has tendencies, or potentialities, towards developing in definite and not in haphazard directions; and these tendencies become actualized during evolution. They are kept in check by inhibiting factors, and on the removal of an inhibition there is an outburst of evolutionary activity; thus evolution is seen to be periodic. Potentialities tend to become exhausted on actualization; but, before this happens, may lead to the exaggeration of a character which, in turn, may cause the extinction of a lineage. Homœomorphy is the expression of common tendencies or potentialities becoming actual along many divergent lineages.

II. This view reflected on to the phenomena of old age and extinction in (*a*) Cretaceous cribrimorph Polyzoa; (*b*) Ammonites; and (*c*) Rugose Corals.

III. The consequences of this view.

A view which ignores, or at least slights, environmental influences is likely to overlook the truth in one direction as far as (so the author believes) a purely environmental or mechanistic view, such as orthodox Darwinism, overlooks it on the other side. As an organism is a synthesis of structure and function, so its structure is a synthesis of expression and impression — expression of potentialities and impression of the environment. A synthesis is not an aggregate, for it transcends the sum of its components. A transcendental theory of evolution would link the field of philosophical biology to the realm of general philosophy.

CORRESPONDENCE.

RECENT PAPERS ON THE DURHAM COALFIELD.

Sir,—In the Geological Magazine of April last (p. 163) I observed a paper by Dr. D. Woolacott relating to the above Coalfield, where he writes of "the little-known Ganister Series" of that district, and I wondered what might be the precise meaning he wished to convey by those words. Three or four coal-seams belonging to that Series (i.e. below the Brockwell Seam) have been vigorously worked for the past thirty years or more. The measures

have been sunk through and bored, perhaps in a hundred places, whilst scores of mining engineers, inspectors, colliery managers (whose success depends largely on their detailed knowledge of the strata of their mines) are and have been engaged in the exploitation of these seams, and we may presume that the sequence must be fairly well known lithologically. And so far as one can gather from his paper, it is solely upon lithological evidence Dr. Woolacott bases his conclusion that the boreholes he describes were in the Ganister Series. The generic names of the fossil plants he gives are quite useless in Coal-measure stratigraphy, and his quaint note that "no trace of any *characteristic fossil* [italics are mine] such as *Aviculopecten papyraceus* was found" leads one to infer that he has not followed recent palæontological work in the Coal-measures, or he would not place so much reliance for zoning purposes on the discovery of *Pterinopecten papyraceus*. It is to be hoped that Dr. Woolacott is in possession of other evidence of higher diagnostic value to warrant his opinion of the horizon reached by the boreholes. A perusal of this paper has suggested a fair reason for the disinclination of some mining people to seek the assistance of the geologists.

In the May issue of the Geological Magazine (pp. 203–211) Drs. Trechmann and Woolacott were constrained "to put definitely on record" the fact of the occurrence of the zone of *Anthracomya phillipsi* in the Coal-measures of Durham. They omitted to mention that this had already been done in the following papers, viz. Geol. Mag., 1905, pp. 536–7, and Trans. Inst. Min. Engineers, vol. xxx, pp. 453–4, 1906, where the stratigraphical significance of the discovery was clearly stated.

J. T. Stobbs.

Stoke-on-Trent.
May 21, 1919.

PRODUCTUS HUMEROSUS IN DOVE DALE.

Sir,—I had the good fortune recently to meet with two specimens of *Productus humerosus* (*P. sublævis*) in Dove Dale (Derbyshire). This discovery seems worthy of record in point of view of the fact that hitherto the species has only been recorded for the Midland area from Caldon Low (Staffs). The Dove Dale examples occurred in a loose limestone block on the screes immediately below Reynard's Cave. In general form the specimens are strongly convex, narrow, and smooth, resembling the narrow form from Caldon Low described in this Magazine for February, 1919, p. 64. The matrix, however, is quite unlike that of the Caldon examples.

J. Wilfrid Jackson.

Manchester Museum.
May 22, 1919.

MOUSTERIAN FLAKE-IMPLEMENTS.

Sir,—I notice that in my letter published in the Geological Magazine for May, p. 240, I am made to speak of "the earlier Palæolithic 'cave' implements", and of "a normal Chellean or